CBM-017
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FINAL REPORT

UTAH COAL CORE METHANE
DESORPTION PROJECT

By

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INTRODUCTION

The Utah Geological and Mineral Survey under a cooperative grant, DE-FG21-80MC14257 as amended, with the Department of Energy, Morgantown Energy Technology Center has collected one hundred fifty two coal core samples for determination of methane content by the "Direct Method". These samples along with available samples from previous work have been examined petrographically to determine possible relationships with gas content. Reflectance, maceral analysis, fluorescence analysis, long proximate, and ultimate analyses have been determined.

CHRONOLOGY

Period: June 1, 1979 thru May 31, 1980

This period was one of active resource definition and exploration drilling by various government and private entities. One hundred and one (101) samples were collected from four different coal fields.

Contract No. DE-FG21-79MC11729

Funding:

Federal:	$51,700.00
UGMS Cost Sharing:	$9,135.00

Purpose: Basic grant to provide for characterization of unmined/unminable coalbeds.

Modification A001

Funding: Decrease program funding.

Federal:	From	$51,700.00	to	$40,230.00
UGMS Cost Sharing:	From	$9,135.00	to	$7,365.00

Purpose: This modification was executed on March 10, 1981 for the purpose of transferring unused funds to grant DE-FG21-80MC14257 for utilization toward the purchase of a microscope for coal petrographic work. A release was signed by Utah Geological and Mineral Survey on March 4, 1981 which closed out this grant.

Period: June 1, 1980 to May 31, 1981

Contract No.: DE-FG21-80MC14257

Funding:

Federal:	$51,525.00
UGMS Cost Sharing:	$7,474.00

Purpose: Basic grant to provide for characterization of unmined/unminable coalbeds.

Amendment No. A001

Period: June 1, 1980 to May 31, 1981

During this period, twenty five (25) samples were collected.

At the Coal Resource Review for Western Basins, a presentation was made by Utah Geological and Mineral Survey concerning samples from the Book Cliffs Coal Field and the observation that Book Cliffs samples significantly hold more residual gas than all other fields examined. Further, because the anomalous amount of residual gas is not readily explainable from topographic or the geologic considerations, the possibility that the maceral composition contributes to the phenomena is paramount. The physical and chemical characteristics are also germane, but all things being equal, they are not significantly different from the other fields. After the Coal Resource Review for Western Basins, a letter detailing the specifications for a microscope/photometer was forwarded along with a request for a change in scope of the grant.

A review of the TRW Uinta Basin Report was completed.

Mapping of the roof geology and coal seam characteristics of the Hardscrabble Canyon #3 Mine commenced.

Maceral analysis, white light, and reflectance analysis of coal core samples was initiated.

It is noteworthy that the Utah Geological and Mineral Survey cost sharing increased significantly with the understanding that at the completion of the grant, Utah Geological and Mineral Survey would ask for unrestricted ownership of the microscope and all supporting equipment.

Funding:

Federal	$62,995.00
UGMS Cost Sharing	$20,569.00

Purpose: The purpose of this modification was to increase the grant budget by transferring funds from DE-FG21-79MC11729 to enable the purchase of a microscope/photometer.

An additional $11,470.00 of federal funds were added to make the total amount awarded $62,995.00

An additional cost sharing by UGMS of $13,094.79 was added to the program budget to make a total cost sharing of $20,569.00.

Amendment A002

Period: June 1, 1981 to May 31, 1982

During this period, seventeen (17) samples were collected.

A review of past sampling was conducted to determine availability for petrographic examination. Sixty five (65) samples of the one hundred sixty two (162) samples from previous work were available. Preparation and examination of these samples was initiated.

Mapping of the roof geology and coal seam characteristics of the Hardscrabble Canyon No. 3 mine was completed during this period.

Mapping of the 7 1/2' Deadman Canyon quadrangle was initiated for the purpose of interpreting the geology in the gassy area of the Book Cliffs and verifying structural and stratigraphic relationships.

Funding:

Federal:	$53,091.00
UGMS Cost Sharing:	$23,307.00

Purpose: Continuance of the grant negotiated in A001 for an additional two years and two phases operationally.

Amendment A003

Period: June 1, 1982 to May 31, 1983

Five (5) surface coal core samples plus twenty six (26) in-mine chip samples and four (4) in-mine coal core samples have been collected during this period.

Mapping of the 7 1/2' Helper, Jump Creek, and Standardville Quadrangles was initiated for the purpose of interpreting the geology in the gassy area of the Book Cliffs and to verify structural and stratigraphic relationships.

In-mine coal chip sampling was initiated in cooperation with Resource Enterprises Incorporated and the Soldier Creek Mine.

Funding:

Federal:	$49,990.68
UGMS Cost Sharing:	$21,755.10

Purpose: Continuance of the grant negotiated in A001.

Amendment A004

Period: June 1, 1983 to September 30, 1983

Funding: No additional funding required.

Purpose: Extension of the grant period to allow for completion of in-mine collection and processing of chip samples and collection of samples in the Vernal Coal Field and in the Book Cliffs Coal Field that occurred on an opportunity basis.

METHODOLOGY & DATA

The process utilized by the Survey for the collection of surface/in-mine coal core/chip samples is best described with a flow diagram depicting the operations, analyses, and evaluation processes:

OPERATIONS	ANALYSES	EVALUATION
Surface/In-mine Drilling		
Site/Strat. Description		
Seal Samples in Desorption Cannisters		
	Gas Composition (As Req.)	Composition Variation
Terminate Desorption		Plot Desorption Rate a. Lost Gas Est. b. Total Gas Desorbed
Core Weight		Calculate a. Gas/Unit Wght. b. Gas/Unit Vol.
	Long Proximate	Ash Content, Fixed Carbon Vol. Matter, % Moisture
	a. Sulfur Forms	a. Pyritic b. Sulfate c. Organic
	Ultimate	Elemental Composition H, C, N, O, S
	Residual Gas Processing	Calculate Residual Gas
Core Sample Prep.		
	Vitrinite Reflectance	Thermal Maturity
	Maceral-White Light	Maceral content by Vol. Adj. to Blue Light Values
	Maceral-Blue Light	Maceral Content(Liptinites Non fluorescence)

In-mine/Srfc. Mapping	Geology, Structure Stratigraphy Depositional Environments, Cleat, Roof Geology.	Reports, Theses, Maps Isopachs

FINAL REPORT

Gas Content, Gas Composition, Petrography, Chemical Analysis, Prospect Evaluation, Report of Mapping and Land Use Maps.

The following is a list of samples collected or examined petrographically under Department of Energy Grant arranged by gas content value.

Sample No.	Geo-coordinates	Coal Field	Coal Zone/Bed	Gas Content
274	NE26-19S- 6E	Wasatch (Sample invalidated)		
169	SE 6-23S- 6E	Emery	A	0.00
170	NE 6-23S- 6E	Emery	A	0.00
173	SE31-22S- 6E	Emery	A	0.00
193	NE15-22S- 6E	Emery	A	0.00
195	SW31-22S- 6E	Emery	A	0.00
196	SW 6-23S- 6E	Emery	A	0.00
217	SW 1-23S- 5E	Emery	A	0.00
223	SW 7-23S- 6E	Emery	A(rider)	0.00
165	NE 6-23S- 6E	Emery	G	0.00
171	SW 6-23S- 6E	Emery	G	0.00
174	SW31-22S- 6E	Emery	G	0.00
221	SE 1-23S- 5E	Emery	G	0.00
168	NE 8-23S- 6E	Emery	I	0.00
188	SE31-22S- 6E	Emery	I	0.00
175	SW31-22S- 6E	Emery	K	0.00
167	NE 8-23S- 6E	Emery	C-D	0.00
172	SW 6-23S- 6E	Emery	C-D	0.00
177	SW31-22S- 6E	Emery	C-D	0.00
181	SE31-22S- 6E	Emery	C-D	0.00
194	SW31-22S- 6E	Emery	C-D	0.00
199	SW 6-23S- 6E	Emery	C-D	0.00
166	NE 6-23S- 6E	Emery	I-J	0.00
176	SW31-22S- 6E	Emery	I-J	0.00
190	NW 1-19S-22E	Sego	Ballard	0.00
301	32-18S- 7E	Wasatch	Blind Canyon	0.00
192	NE 1-19S-22E	Sego	Chesterfield	0.00
307	SW14-13S- 6E	Wasatch	Flat Canyon	0.00
204	NW 9-13S-11E	Book Cliffs	Gilson	0.00
228	NE 2-22S- 4E	Wasatch	Hiawatha	0.00
281	SW20-20S- 5E	Wasatch	Hiawatha	0.00
282	NE13-21S- 4E	Wasatch	Hiawatha	0.00
299		Wasatch	Hiawatha	0.00
202	SW 5-22S- 5E	Wasatch	Hiawatha(u)	0.00
203	SW 8-22S- 5E	Wasatch	Hiawatha(u)	0.00
211	SW 5-22S- 5E	Wasatch	Hiawatha(u)	0.00
212	SW 2-21S- 5E	Wasatch	Hiawatha(u)	0.00
216	SE 5-22S- 5E	Wasatch	Hiawatha(u)	0.00
275	SE33-20S- 5E	Wasatch	Hiawatha(u)	0.00
280	SW20-20S- 5E	Wasatch	Hiawatha(u)	0.00
309	NW30-21S- 5E	Wasatch	Hiawatha(u)	0.00
310	SE25-21S- 4E	Wasatch	Hiawatha(u)	0.00
284	SE27-22S- 4E	Wasatch	Ivie?	0.00
283	SW20-20S- 5E	Wasatch	Muddy No. 1	0.00
288	2-13S- 6E	Wasatch	O'Connor	0.00
226	SE14-13S- 6E	Wasatch	O'Connor(l)	0.00
227	NE35-13S- 6E	Wasatch	O'Connor(l)	0.00
286	NW 1-13S- 6E	Wasatch	O'Connor(l)	0.00
224	SE14-13S- 6E	Wasatch	O'Connor(u)	0.00

238	SW35-13S- 6E	Wasatch	O'Connor(u)	0.00
191	NW 1-19S-22E	Sego	Palisade	0.00
205	NW 1-19S-22E	Sego	Unknown	0.00
273	NW35-19S- 6E	Wasatch	Unknown	0.00
277	NW 2-19S- 6E	Wasatch	Unknown	0.00
295	30-18S- 7E	Wasatch	Unknown	0.00
296		Wasatch	Unknown	0.00
293	30-18S- 7E	Wasatch	Bear Canyon	0.02
5	SE 3-19S- 6E	Wasatch	Bear Canyon	0.06
308	NW25-21S- 4E	Wasatch	Hiawatha(u)	0.06
182	SW 6-23S- 6E	Emery	A	0.10
178	SW31-22S- 6E	Emery	G	0.10
179	NW 6-23S- 6E	Emery	C-D	0.10
189	SW 6-23S- 6E	Emery	I-J	0.10
197	SW31-22S- 6E	Emery	I-J	0.10
68	SE 5-13S-10E	Book Cliffs	Castlegate A	0.10
272	SE33-20S- 5E	Wasatch	Hiawatha	0.10
279	SE21-19S- 6E	Wasatch	Hiawatha	0.10
291	SW26-23S- 3E	Wasatch	Hiawatha	0.10
292	NE27-23S- 3E	Wasatch	Hiawatha	0.10
200	NE 2-22S- 4E	Wasatch	Hiawatha(u)	0.10
218	SW 7-22S- 5E	Wasatch	Hiawatha(u)	0.10
225	NE35-13S 6E	Wasatch	McKinnon	0.10
242	SE22-13S- 6E	Wasatch	O'Connor(l)	0.10
305	SW14-13S- 6E	Wasatch	O'Connor(u)	0.10
306	SW14-13S- 6E	Wasatch	O'Connor(u)	0.10
268	SE36-16S-14E	Book Cliffs	Sunnyside	0.10
1	SW22-16S- 6E	Wasatch	Hiawatha	0.18
186	SW 6-23S- 6E	Emery	A	0.20
208	SW 8-23S- 6E	Emery	A	0.20
207	SW14-22S- 6E	Emery	I	0.20
187	SW 8-23S- 6E	Emery	C-D	0.20
232	NW32-18S- 7E	Wasatch	Hiawatha	0.20
215	SE 2-21S- 5E	Wasatch	Hiawatha(u)	0.20
222	SE 8-22S- 5E	Wasatch	Hiawatha(u)	0.20
276	NW26-19S- 6E	Wasatch	Hiawatha(u)	0.20
240	SE26-13S- 6E	Wasatch	O'Connor(l)	0.20
247	SE10-13S- 6E	Wasatch	O'Connor(l)	0.20
285	1-13S- 6E	Wasatch	O'Connor(l)	0.20
316	SE14-19S- 5E	Wasatch	Hiawatha	0.21
300	1-18S- 6E	Wasatch	Hiawatha	0.24
19	NE23-17S- 7E	Wasatch	Hiawatha	0.26
33	NE14-13S- 6E	Wasatch	Flat Canyon	0.27
220	SE 1-23S- 5E	Emery	I	0.30
206	NE15-22S- 6E	Emery	I-J	0.30
253	SW 3-17S- 7E	Wasatch	Blind Canyon	0.30
95	NW 5-13S- 9E	Book Cliffs	Castlegate A	0.30
233	SW24-21S- 4E	Wasatch	Hiawatha	0.30
271	NE15-19S- 6E	Wasatch	Hiawatha	0.30
290	SW35-16S- 6E	Wasatch	Hiawatha	0.30
304	31-18S- 7E	Wasatch	Hiawatha(u)	0.30
239	SW35-13S- 6E	Wasatch	O'Connor(l)	0.30
243	SE22-13S- 6E	Wasatch	O'Connor(l)	0.30
287	NE 1-13S- 6E	Wasatch	O'Connor(l)	0.30
213	NW 9-13S-11E	Book Cliffs	Rock Canyon	0.30

250	NW 9-13S-11E	Book Cliffs	Sunnyside	0.30
267	NE 1-17S-14E	Book Cliffs	Sunnyside	0.30
302	32-18S- 7E	Wasatch	Hiawatha(u)	0.34
201	SW14-22S- 6E	Emery	A	0.40
180	SW31-22S- 6E	Emery	J	0.40
183	SW 8-23S- 6E	Emery	C-D	0.40
198	NE 6-23S- 6E	Emery	C-D	0.40
297	5-19S- 7E	Wasatch	Blind Canyon	0.40
245	NW 1-19S-22E	Sego	Chesterfield	0.40
269	NE22-19S- 6E	Wasatch	Hiawatha	0.40
270	11-19S- 6E	Wasatch	Hiawatha	0.40
219	SW24-21S- 4E	Wasatch	Hiawatha(u)	0.40
234	SW 5-22S- 5E	Wasatch	Muddy	.40
251	SE22-13S- 6E	Wasatch	O'Connor(l)	0.40
244	SE22-13S- 6E	Wasatch	O'Connor(u)	0.40
236	NW 1-19S-22E	Sego	Palisade	0.40
294	30-18S- 7E	Wasatch	Bear Canyon	0.41
298	6-19S- 7E	Wasatch	Blind Canyon	0.41
20	NE23-17S- 7E	Wasatch	Blind Canyon	0.45
303	31-18S- 7E	Wasatch	Blind Canyon	0.48
249	SE 1-23S- 5E	Emery	A	0.50
184	SW31-22S- 6E	Emery	C-D	0.50
231	NW32-18S- 7E	Wasatch	Blind Canyon	0.60
278	NW 2-19S- 6E	Wasatch	Hiawatha	0.60
235	NW12-23S- 5E	Emery	Unknown	0.60
75	SE 6-13S- 9E	Book Cliffs	Castlegate C	0.67
21	NE36-12S-10E	Book Cliffs	Castlegate C	0.70
74	SE 6-13S- 9E	Book Cliffs	Castlegate D	0.72
248	NW 6-23S- 6E	Emery	G	0.80
241	SE26-13S- 6E	Wasatch	McKinnon	0.80
17	SW17-14S-14E	Book Cliffs	Sunnyside	0.87
256	SW31-17S-23E	Sego	Unknown	0.90
78	NW 6-13S- 9E	Book Cliffs	Castlegate B	0.93
185	SW 8-23S- 6E	Emery	G	1.00
214	SE28-12S- 9E	Book Cliffs	Castlegate A	1.00
77	SE 6-13S- 9E	Book Cliffs	Castlegate B	1.02
93	NE 6-13S- 9E	Book Cliffs	Castlegate B(l)	1.03
230	SW 7-23S- 6E	Emery	A	1.10
210	SW 6-23S- 6E	Emery	G	1.10
70	NE 5-13S-10E	Book Cliffs	Castlegate B	1.10
289	SW27-16S- 6E	Wasatch	Hiawatha	1.10
23	SW31-12S-10E	Book Cliffs	Castlegate D	1.12
22	SW31-12S-10E	Book Cliffs	Castlegate Unk.	1.17
85	NE 2-13S- 8E	Book Cliffs	Castlegate B	1.24
99	SE 3-13S-10E	Book Cliffs	Castlegate A	1.26
24	SW31-12S-10E	Book Cliffs	Castlegate D	1.26
11	10-13S-12E	Book Cliffs	Gilson	1.30
12	SW17-14S-14E	Book Cliffs	Sunnyside	1.89
263	SE22-13S- 6E	Wasatch	O'Connor(u)	1.30
64	SE 5-13S-10E	Book Cliffs	Castlegate C	1.31
2	SE 3-17S- 6E	Wasatch	Hiawatha	1.33
25	SW31-12S-10E	Book Cliffs	Kenilworth	1.35
98	SE 3-13S-10E	Book Cliffs	Castlegate B	1.40
65	SE 5-13S-10E	Book Cliffs	Castlegate C	1.40
265	NE15-22S- 6E	Emery	G	1.50

86	SW28-12S- 9E	Book Cliffs	Castlegate D	1.50
102	SE32-12S- 9E	Book Cliffs	Subseam 2	1.50
229	SE33-12S- 9E	Book Cliffs	Castlegate D	1.60
18	NE23-17S- 7E	Wasatch	Hiawatha	1.65
69	NE 5-13S-10E	Book Cliffs	Castlegate C	1.66
13	SW17-14S-14E	Book Cliffs	Sunnyside	1.69
92	NE 6-13S- 9E	Book Cliffs	Castlegate B(u)	1.75
252	SE22-13S- 6E	Wasatch	O'Connor(l)	1.80
258	SW34-12S-12E	Book Cliffs	Rock Canyon	1.80
97	NW 5-13S- 9E	Book Cliffs	Subseam 2	1.91
257	SW14-22S- 6E	Emery	C-D	2.00
259	SE26-13S- 6E	Wasatch	O'Connor(u)	2.00
71	NE 5-13S-10E	Book Cliffs	Castlegate A	2.13
27	SW31-12S-10E	Book Cliffs	Castlegate C	2.13
108	NE35-12S-10E	Book Cliffs	Kenilworth	2.20
76	NE28-12S- 9E	Book Cliffs	Subseam 1	2.20
67	SE 5-13S-10E	Book Cliffs	Castlegate A	2.23
246	SE33-12S- 9E	Book Cliffs	Castlegate A	2.30
103	SE32-12S- 9E	Book Cliffs	Subseam 3	2.30
90	SW28-12S- 9E	Book Cliffs	Subseam 2	2.35
66	SE 5-13S-10E	Book Cliffs	Castlegate A	2.59
209	SW 6-23S- 6E	Emery	I-J	2.60
109	NE35-12S-10E	Book Cliffs	Kenilworth	2.64
100	NE12-13S-10E	Book Cliffs	Castlegate A	2.74
10	4-13S-12E	Book Cliffs	Rock Canyon(u)	2.77
254	SE33-12S- 9E	Book Cliffs	Castlegate C	2.80
314	NW16-13S-12E	Book Cliffs	Rock Canyon	2.83
311	SE25-13S-12E	Book Cliffs	Rock Canyon	2.94
101	SE32-12S- 9E	Book Cliffs	Castlegate D	2.95
94	NW 5-13S- 9E	Book Cliffs	Castlegate B	3.00
266	NE 6-23S- 6E	Emery	G	3.30
16	SW17-14S-14E	Book Cliffs	Sunnyside	3.36
315	NW16-13S-12E	Book Cliffs	Gilson	3.50
14	SW17-14S-14E	Book Cliffs	Sunnyside	3.69
80	SE28-12S- 9E	Book Cliffs	Castlegate A	3.90
15	SW17-14S-14E	Book Cliffs	Sunnyside	4.04
264	SE31-22S- 6E	Emery	G	4.70
312	SE15-13S-12E	Book Cliffs	Gilson	4.71
8	4-13S-12E	Book Cliffs	Sunnyside	4.76
237	SE28-12S- 9E	Book Cliffs	Castlegate D	4.80
261	SE34-12S-12E	Book Cliffs	Sunnyside(l)	5.30
9	4-13S-12E	Book Cliffs	Rock Canyon(l)	5.39
79	SE28-12S- 9E	Book Cliffs	Castlegate D	5.57
262	SE34-12S-12E	Book Cliffs	Gilson	6.60
255	SE33-12S- 9E	Book Cliffs	Kennilworth	6.60
88	SW28-12S- 9E	Book Cliffs	Castlegate A	7.08
81	SE28-12S- 9E	Book Cliffs	Castlegate A	7.15
89	SW28-12S- 9E	Book Cliffs	Subseam 1	7.40
313	SE13-13S-12E	Book Cliffs	Rock Canyon	7.46
82	SE28-12S- 9E	Book Cliffs	Subseam 1	8.25
83	SE28-12S- 9E	Book Cliffs	Subseam 2	8.43
72	NE28-12S- 9E	Book Cliffs	Castlegate A	8.93
73	NE28-12S- 9E	Book Cliffs	Castlegate A	9.40
260	SE34-12S-12E	Book Cliffs	Gilson	9.40
114	NW27-12S-10E	Book Cliffs	Castlegate C	10.63

31	SW26-12S-10E	Book Cliffs	Kenilworth	10.94
113	NW27-12S-10E	Book Cliffs	Kenilworth	11.02

GAS CONTENT ANALYSIS

The approach used to collect coal core for determination of gas content is by financial necessity one which is donor dependent. Consequently, a structured research plan for development of data on a particular coal field is not possible unless you plan a concurrent drilling program for the area of interest. The random nature of the collected samples should be considered with the foregoing statement in mind. The procedure used to measure the gas content of the collected coal cores is that specified in the U. S. Bureau of Mines Report of Investigation 8515 by W. P. Diamond and J. R. Levine. The "Direct Method" of determination was used on all samples.

The following is a tabular presentation of the elements of gas content analysis. Sixty five (65) samples from previous work are included in this tabulation because petrographic work was done on them.

GAS CONTENT ANALYSIS

Sample No.	1	2	5	8	9	10
Time Sealed (days)	53	856	39	3	51	60
Depth (ft.)	872.8	617.0	971.3	1,798.8	2,353.1	2,340.2
Lost Gas (cm^3)	29.0	20.0	3.0	274.0	55.0	61.0
Desorbed Gas (cm^3)	53.0	856.0	39.0	2,628.0	3,277.0	1,813.0
Residual Gas (cm^3)	54.0	584.0	28.0	1,853.0	2,129.0	1,121.0
Gas Content (cm^3/gm)	0.18	1.33	0.06	4.76	5.39	2.77

Sample No.	13	14	15	16	17	18
Time Sealed (days)	103	114	114	82	68	42
Depth (ft.)	43.0	64.0	70.2	44.5	47.0	113.9
Lost Gas (cm^3)	3.0	27.0	30.0	38.0	10.0	35.0
Desorbed Gas (cm^3)	1,426.0	3,685.0	3,696.0	3,215.0	592.0	326.0
Residual Gas (cm^3)	952.0	2,474.0	2,484.0	2,168.0	401.0	240.0
Gas Content (cm^3/gm)	1.69	3.69	4.04	3.36	0.87	1.65

Sample No.	19	20	21	22	23	24
Time Sealed (days)	9	12	42	59	59	84
Depth (ft.)	116.8	152.0	1,249.0	129.6	160.7	170.1
Lost Gas (cm^3)	40.0	27.0	10.0	73.0	51.0	33.0
Desorbed Gas (cm^3)	46.0	86.0	320.0	497.0	366.0	450.0
Residual Gas (cm^3)	70.0	75.0	220.0	380.0	278.0	322.0
Gas Content (cm^3/gm)	0.26	0.45	0.70	1.17	1.12	1.26

Sample No.	25	27	31	33	64	65
Time Sealed (days)	83	82	96	18	43	60
Depth (ft.)	245.0	300.5	2,449.5	1,368.2	556.5	563.0
Lost Gas (cm^3)	40.0	224.0	262.0	51.0	64.0	110.0
Desorbed Gas (cm^3)	479.0	794.0	3,912.0	56.0	451.0	682.0
Residual Gas (cm^3)	346.0	679.0	2782.0	71	594.3	792.4
Gas Content (cm^3/gm)	1.35	2.13	10.94	0.27	1.31	1.40

Sample No.	66	67	68	69	70	71
Time Sealed (days)	60	60	11	26	26	26
Depth (ft.)	591.8	592.8	193.5	898.4	972.8	1,004.0
Lost Gas (cm^3)	66.0	68.0	0.0	800.0	75.0	57.0
Desorbed Gas (cm^3)	708.0	720.0	108.0	213.0	318.0	695.0
Residual Gas (cm^3)	1,060.5	916.8	0.0	438.5	475.2	1177.8
Gas Content (cm^3/gm)	2.59	2.23	0.10	1.66	1.10	2.13

Sample No.	72	73	74	75	76	77
Time Sealed (days)	157	202	20	20	5	18
Depth (ft.)	2,642.7	2,656.3	149.0	198.0	2,821.4	316.3
Lost Gas (cm^3)	69.0	80.0	0.0	0.0	0.0	0.0
Desorbed Gas (cm^3)	7,568.0	8,956.0	294.0	199.0	0.0	256.0
Residual Gas (cm^3)	856.0	220.0	679.0	601.5	2,303.4	469.6
Gas Content (cm^3/gm)	8.93	9.40	0.50	0.50	2.20	0.66

Sample No.	78	79	80	81	82	83
Time Sealed (days)	12	105	5	178	122	90
Depth (ft.)	352.5	1,135.8	1,196.6	1,217.0	1,395.3	1,436.6
Lost Gas (cm^3)	0.0	90.0	0.0	178.0	153.0	187.0
Desorbed Gas (cm^3)	85.0	5,747.0	5.0	11,084.0	6,217.0	5,643.0
Residual Gas (cm^3)	480.8	978.0	4,687.8	493.3	683.0	1,812.0
Gas Content (cm^3/gm)	0.79	0.80	3.90	7.15	8.25	8.43

Sample No.	85	86	89	90	92	93
Time Sealed (days)	5	8	194	40	41	41
Depth (ft.)	440.6	1,101.2	1,503.9	1,514.4	503.4	511.4
Lost Gas (cm^3)	0.0	0.0	170.0	92.0	70.0	37.0
Desorbed Gas (cm^3)	44.0	0.0	9,735.0	1,035.0	680.0	592.0
Residual Gas (cm^3)	1,069.2	2,160.6	1,008.4	1,956.2	635.0	396.9
Gas Content (cm^3/gm)	1.24	1.50	7.40	2.35	0.51	1.03

Sample No.	94	95	97	98	99	100
Time Sealed (days)	33	5	13	9	10	110
Depth (ft.)	737.3	778.9	936.9	775.9	825.7	569.7
Lost Gas (cm^3)	130.0	0.0	40.0	0.0	69.0	95.0
Desorbed Gas (cm^3)	787.0	0.0	96.0	0.0	82.0	2,241.0
Residual Gas (cm^3)	1,378.0	362.0	2,324.0	1,331.7	1,046.3	287.0
Gas Content (cm^3/gm)	3.00	0.30	1.91	1.40	1.26	2.74

Sample No.	101	102	103	108	109	113
Time Sealed (days)	6	5	5	9	13	114
Depth (ft.)	1,307.6	1,742.7	1,762.1	2,820.6	2,827.2	3,176.9
Lost Gas (cm^3)	44.0	0.0	0.0	0.0	95.0	580.0
Desorbed Gas (cm^3)	93.0	0.0	0.0	2.0	661.0	6,413.0
Residual Gas (cm^3)	2,619.4	1,445.8	2,282.1	1,368.4	1,368.5	270.0
Gas Content (cm^3/gm)	2.95	1.50	2.30	2.20	2.64	11.02

Sample No.	114	162	165	166	167	168
Time Sealed (days)	112	23	5	6	12	12
Depth (ft.)	3,292.4	1,938.7	549.9	465.9	259.2	143.4
Lost Gas (cm^3)	420.0	98.0	0.0	0.0	0.0	0.0
Desorbed Gas (cm^3)	6,964.0	247.0	0.0	0.0	0.0	0.0
Residual Gas (cm^3)	300.0	2,086.6	0.0	0.0	0.0	0.0
Gas Content (cm^3/gm)	10.63	2.68	0.0	0.0	0.0	0.0

Sample No.	169	170	171	172	173	174
Time Sealed (days)	13	5	5	5	5	6
Depth (ft.)	755.3	701.6	571.1	653.5	538.8	755.8
Lost Gas (cm^3)	0.0	0.0	0.0	0.0	0.0	0.0
Desorbed Gas (cm^3)	0.0	0.0	0.0	0.0	0.0	0.0
Residual Gas (cm^3)	0.0	0.0	0.0	0.0	0.0	0.0
Gas Content (cm^3/gm)	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	175	176	177	178	179	180
Time Sealed (days)	5	5	5	19	18	9
Depth (ft.)	664.8	680.4	815.4	546.7	706.3	642.8
Lost Gas (cm^3)	0.0	0.0	0.0	19.0	23.0	88.0
Desorbed Gas (cm^3)	0.0	0.0	0.0	17.0	23.0	63.0
Residual Gas (cm^3)	0.0	0.0	0.0	0.0	0.0	4.0
Gas Content (cm^3/gm)	0.0	0.0	0.0	0.1	0.1	0.4

Sample No.	181	182	183	184	185	186
Time Sealed (days)	9	8	31	20	35	22
Depth (ft.)	483.0	688.8	278.8	597.6	247.5	702.3
Lost Gas (cm^3)	0.0	19.0	121.0	155.0	360.0	101.0
Desorbed Gas (cm^3)	1.0	20.0	138.0	183.0	195.0	105.0
Residual Gas (cm^3)	0.0	*	0.0	40.4	0.0	0.0
Gas Content (cm^3/gm)	0.0	*	0.40	0.50	1.00	0.20

Sample No.	187	188	189	190	191	192
Time Sealed (days)	25	14	7	7	6	10
Depth (ft.)	294.4	363.6	585.0	352.8	427.6	314.5
Lost Gas (cm^3)	25.0	5.0	70.0	0.0	0.0	0.0
Desorbed Gas (cm^3)	74.0	19.0	35.0	0.0	0.0	0.0
Residual Gas (cm^3)	0.0	*	*	0.0	0.0	0.0
Gas Content (cm^3/gm)	0.20	*	*	0.0	0.0	0.0

Sample No.	193	194	195	196	197	198
Time Sealed (days)	7	8	10	9	19	24
Depth (ft.)	777.5	833.8	859.6	749.2	657.5	633.2
Lost Gas (cm^3)	0.0	0.0	0.0	0.0	19.0	59.0
Desorbed Gas (cm^3)	0.0	0.0	0.0	0.0	33.0	151
Residual Gas (cm^3)	11.0	0.0	*	*	0.0	0.0
Gas Content (cm^3/gm)	0.0	0.0	*	*	0.10	0.40

Sample No.	199	200	201	202	203	204
Time Sealed (days)	6	17	20	6	6	6
Depth (ft.)	688.8	886.0	553.7	946.5	841.0	599.9
Lost Gas (cm^3)	0.0	21.0	72.0	0.0	0.0	0.0
Desorbed Gas (cm^3)	0.0	77.0	201.0	0.0	0.0	0.0
Residual Gas (cm^3)	*	0.0	0.0	0.0	0.0	56.4
Gas Content (cm^3/gm)	*	0.10	0.40	0.00	0.00	0.00

Sample No.	205	206	207	208	209	210
Time Sealed (days)	11	22	22	43	34	23
Depth (ft.)	468.7	650.8	375.9	323.7	494.5	641.7
Lost Gas (cm^3)	24.0	80.0	3.0	80.0	204.0	496.0
Desorbed Gas (cm^3)	18.0	80.0	24.0	87.0	696.0	81.0
Residual Gas (cm^3)	0.0	0.0	98.6	0.0	0.0	85.2
Gas Content (cm^3/gm)	0.00	0.30	0.18	0.20	2.61	1.14

Sample No.	211	212	213	214	215	216
Time Sealed (days)	5	14	15	14	16	5
Depth (ft.)	907.8	937.0	404.8	1,187.8	934.4	879.9
Lost Gas (cm^3)	0.0	0.0	200.0	195.0	19.0	0.0
Desorbed Gas (cm^3)	1.0	2.0	256.0	423.0	258.5	11.0
Residual Gas (cm^3)	0.0	0.0	63.1	60.7	0.0	0.0
Gas Content (cm^3/gm)	0.00	0.00	0.30	1.00	0.20	0.00

Sample No.	217	218	219	220	221	222
Time Sealed (days)	5	10	10	7	5	8
Depth (ft.)	847.3	793.6	1,159.1	601.7	671.9	792.0
Lost Gas (cm^3)	0.0	125.0	179.0	75.0	0.0	60.0
Desorbed Gas (cm^3)	0.0	50.0	332.0	92.0	0.0	56.0
Residual Gas (cm^3)	0.0	0.0	0.0	0.0	0.0	0.0
Gas Content (cm^3/gm)	0.00	0.10	0.40	0.30	0.00	0.20

Sample No.	223	224	225	226	227	228
Time Sealed (days)	5	12	10	6	5	46
Depth (ft.)	514.5	514.6	750.6	690.8	1,213.0	911.2
Lost Gas (cm^3)	0.0	0.0	32.0	0.0	0.0	0.0
Desorbed Gas (cm^3)	0.0	17.0	18.0	1.0	0.0	43.0
Residual Gas (cm^3)	0.0	0.0	0.0	0.0	0.0	0.0
Gas Content (cm^3/gm)	0.00	0.00	0.10	0.00	0.00	0.00

Sample No.	229	230	231	232	233	234
Time Sealed (days)	73	9	18	18	21	34
Depth (ft.)	657.4	526.6	1,021.1	1,089.3	1,175.6	744.3
Lost Gas (cm^3)	20.0	139.0	95.0	129.0	150.0	42.0
Desorbed Gas (cm^3)	799.0	0.0	430.0	95.0	309.0	453.0
Residual Gas (cm^3)	357.5	0.0	0.0	0.0	0.0	0.0
Gas Content (cm^3/gm)	1.60	1.10	0.60	0.20	0.30	0.40

Sample No.	235	236	237	238	239	240
Time Sealed (days)	21	44	64	6	19	14
Depth (ft.)	548.9	436.9	957.9	577.3	611.2	660.3
Lost Gas (cm^3)	106.0	129.0	1,420.0	0.0	0.0	78.0
Desorbed Gas (cm^3)	180.0	412.0	2,278.0	0.0	339.0	30.0
Residual Gas (cm^3)	0.0	9.9	120.8	0.0	0.0	0.0
Gas Content (cm^3/gm)	0.60	0.40	4.80	0.00	0.30	0.20

Sample No.	241	242	243	244	245	246
Time Sealed (days)	16	15	15	16	96	116
Depth (ft.)	200.2	996.5	1,069.4	992.5	329.9	963.7
Lost Gas (cm^3)	129.0	51.0	111.0	0.0	140.0	182.0
Desorbed Gas (cm^3)	150.0	31.0	225.0	258.0	410.0	1,310.0
Residual Gas (cm^3)	0.0	0.0	0.0	0.0	0.0	50.5
Gas Content (cm^3/gm)	0.80	0.10	0.30	0.40	0.40	2.30

Sample No.	247	248	249	250	251	252
Time Sealed (days)	16	117	85	111	61	47
Depth (ft.)	1,997.7	663.4	781.3	395.7	1,181.5	1,173.6
Lost Gas (cm^3)	150.0	14.0	6.0	5.0	102.0	661.0
Desorbed Gas (cm^3)	95.0	365.0	311.0	375.0	290.0	637.0
Residual Gas (cm^3)	0.0	0.0	0.0	0.0	0.0	0.0
Gas Content (cm^3/gm)	0.20	0.80	0.50	0.30	0.40	1.80

Sample No.	253	254	255	256	257	258
Time Sealed (days)	13	138	168	152	145	12
Depth (ft.)	191.3	724.9	766.0	432.3	539.9	2,866.9
Lost Gas (cm^3)	321.0	30.0	1,295.0	257.0	201.0	852.0
Desorbed Gas (cm^3)	130.0	1,756.0	3,159.0	1,101.0	1,410.0	840.0
Residual Gas (cm^3)	0.0	0.0	2.5	0.0	0.0	60.4
Gas Content (cm^3/gm)	0.30	2.80	6.60	0.90	2.00	1.80

Sample No.	259	260	261	262	263	264
Time Sealed (days)	65	118	60	77	128	214
Depth (ft.)	605.3	2,935.0	2,719.7	3,097.0	944.5	453.0
Lost Gas (cm^3)	349.0	809.0	1,895.0	1,085.0	161.0	161.0
Desorbed Gas (cm^3)	389.0	3,228.0	1,095	2,346.0	725.0	1,328.0
Residual Gas (cm^3)	0.0	43.3	0.0	65.5	0.0	0.0
Gas Content (cm^3/gm)	2.00	9.40	5.30	6.60	1.30	4.70

Sample No.	265	266	267	268	269	270
Time Sealed (days)	200	237	36	28	6	28
Depth (ft.)	684.5	517.6	855.3	858.3	1,002.6	1,089.7
Lost Gas (cm^3)	18.0	0.0	116.0	82.0	216.0	141.0
Desorbed Gas (cm^3)	583.0	915.0	132.0	58.0	38.0	277.0
Residual Gas (cm^3)	0.0	18.7	0.0	0.0	0.0	0.0
Gas Content (cm^3/gm)	1.50	3.30	0.30	0.10	0.40	0.40

Sample No.	271	272	273	275	276	277
Time Sealed (days)	31	18	16	21	12	11
Depth (ft.)	1316.2	1,057.6	951.8	1,022.9	1,106.2	1,435.4
Lost Gas (cm^3)	40.0	84.0	0.0	0.0	102.0	0.0
Desorbed Gas (cm^3)	265.0	105.0	0.0	60.0	30.0	5.0
Residual Gas (cm^3)	0.0	0.0	0.0	0.0	0.0	0.0
Gas Content (cm^3/gm)	0.30	0.10	0.00	0.00	0.20	0.00

Sample No.	278	279	280	281	282
Time Sealed (days)	10	19	15	14	18
Depth (ft.)	1,438.6	1,103.5	1,646.8	1,677.5	1338.0
Lost Gas (cm^3)	145.0	40.0	19.0	0.0	105.0
Desorbed Gas (cm^3)	83.0	72.0	5.0	0.0	40.0
Residual Gas (cm^3)	0.0	0.0	0.0	0.0	0.0
Gas Content (cm^3/gm)	0.60	0.10	0.02	0.00	0.10

Sample No.	284	285	286	287	288
Time Sealed (days)	9	11	6	14	19
Depth (ft.)	599.0	519.6	383.0	331.4	499.8
Lost Gas (cm^3)	0.0	99.0	13.0	42.0	0.0
Desorbed Gas (cm^3)	0.0	99.0	10.0	85.0	27.0
Residual Gas (cm^3)	0.0	0.0	0.0	0.0	0.0
Gas Content (cm^3/gm)	0.01	0.17	0.00	0.30	0.00

Sample No.	290	291	292	293	294
Time Sealed (days)	8	21	31	20	148
Depth (ft.)	719.0	545.8	619.2	1,315.8	1,302.8
Lost Gas (cm^3)	140.0	61.0	0.0	10.0	4.0
Desorbed Gas (cm^3)	0.0	0.0	38.0	11.0	402.0
Residual Gas (cm^3)	0.0	0.0	0.0	0.0	0.0
Gas Content (cm^3/gm)	0.30	0.10	0.07	0.02	0.41

Sample No.	314	315	316
Time Sealed (days)	41	24	16
Depth (ft.)	1,618.0	1,679.2	1,015.9
Lost Gas (cm^3)	129.0	84.0	125.0
Desorbed Gas (cm^3)	1,546.0	615.0	69.0
Residual Gas (cm^3)	889.9	639.7	0.0
Gas Content (cm^3/gm)	2.83	3.50	0.21

PETROGRAPHIC ANALYSIS - COAL

Two hundred seventeen (217) samples which include sixty five (65) samples from previous work have been examined petrographically. Reflectance analysis and maceral analysis (white-light and fluorescence) have been accomplished in accordance with established standards.

Reflectance Analysis - Reflectance was measured to determine coal maturation or rank and for comparison with rank as determined by the standard of classification by the American Society for Testing and Materials ANSI/ASTM D388-77. Reflectance measurements were determined utilizing a Leitz Ortholux II microscope with a MPV compact photometer at 500X magnification using a 50X oil immersion objective. The procedure outlined in ASTM 2798-79 was adhered to while measuring reflectance. Reflectance measurements are included in the table under White Light Analysis.

Maceral Analysis -

White Light Analysis.- Maceral composition was determined with the use of a Leitz Ortholux II microscope. Crushed pellets were read at 500X using 10X occulars and a 50X oil immersion objective with oil of refractive index 1.5180. In general, procedures were adhered to as delineated in ASTM D2799-72 except, the components counted were expanded to include Psuedovitrinite, Sporinite, Cutinite, Macrinite and Sclerotinite. The occurrence of mineral matter, pyrite, voids, and epoxy under any of the counting points was not included in the total

The total volume percentage, except mineral matter, was counted and recorded for each pellet. A comparison of the average differ- ence of the values between two pellets of the same sample had to match within 2.0 percent; however, only 500 points were counted on each pellet. If agreement was not obtained, the pellets were recounted. The white light maceral composition of the samples reported in the following table have been adjusted to account for additional macerals as identified by fluorescence analysis.

Blue light maceral analysis more accurately records the liptinite content while grouping the non-fluorescing macerals (vitrinite and inertinite) into one category. By combining the results of the white light and blue light analysis, a more accurate measure of maceral composition is obtained. The white light analysis has been adjusted to account for the improved liptinite count as follows: Total Non-Liptinite in Blue Light (%), divided by Total Non-Liptinite in White Light (%), times White Light Maceral(%), equals Adjusted White Light Value (%).

WHITE LIGHT ANALYSIS

Sample No.	1	2	5	8	9	10	11	12
Reflectance (%Mean Max. in oil)	5.79	4.62	5.37	7.27	7.80	7.62	7.15	8.01
Vitrinite	62.1	67.8	65.9	54.5	59.9	61.1	63.3	57.2
Psuedo-Vitrinite	15.7	6.6	9.7	26.0	19.4	14.8	14.7	29.5
Resinite	5.4	5.2	5.3	2.7	3.0	4.5	5.0	2.9
Micrinite	1.0	2.3	1.1	1.4	1.8	2.0	1.2	1.4
SemiFusinite	3.3	10.4	9.1	9.9	10.6	10.3	10.0	2.7
Fusinite	1.0	2.3	1.1	2.3	1.0	2.0	1.7	0.8
Sporinite	8.4	3.9	5.5	1.1	3.0	3.7	2.4	3.2
Cutinite	2.2	1.3	2.1	1.6	1.0	1.2	1.4	2.2
Macrinite	0.6	0.1	0.2	0.2	0.3	0.4	0.1	0.1
Sclerotinite	0.3	0.1	0.0	0.0	0.0	0.0	0.2	0.0

Sample No.	13	14	15	16	17	18	19	20
Reflectance (%Mean Max. in oil)	8.30	8.37	8.34	7.86	8.30	5.88	5.50	6.49
Vitrinite	59.1	63.6	64.5	64.1	60.7	67.5	65.3	60.6
Psuedo-Vitrinite	22.7	19.3	18.6	24.0	26.6	14.7	15.8	15.6
Resinite	3.0	2.5	2.6	2.3	1.6	3.7	3.3	6.4
Micrinite	1.3	1.4	1.8	0.9	1.6	3.0	2.8	3.4
SemiFusinite	8.8	7.5	6.5	1.2	1.6	3.7	2.8	7.6
Fusinite	1.5	2.4	1.7	0.2	0.6	1.0	0.9	2.3
Sporinite	2.4	1.7	2.7	3.0	3.7	4.7	7.3	2.4
Cutinite	1.0	1.3	1.4	4.1	3.1	1.5	1.5	1.3
Macrinite	0.2	0.2	0.1	0.0	0.3	0.0	0.1	0.3
Sclerotinite	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.1

Sample No.	21	22	23	24	25	27	31	33
Reflectance (%Mean Max. in oil)	7.29	6.44	7.23	6.49	6.72	6.96	7.50	5.90
Vitrinite	62.2	47.2	53.6	63.9	55.9	54.3	56.5	71.6
Psuedo-Vitrinite	9.3	41.3	35.2	11.5	13.9	32.4	13.8	15.0
Resinite	2.9	2.0	1.7	5.4	2.6	2.7	1.3	1.5
Micrinite	3.4	5.4	6.4	4.0	3.7	4.3	6.9	3.4
SemiFusinite	17.5	1.7	1.5	8.1	12.7	4.1	15.0	1.2
Fusinite	2.5	0.6	0.3	0.9	4.6	1.0	2.4	0.6
Sporinite	1.4	1.4	1.0	3.5	5.5	1.1	3.3	5.8
Cutinite	0.8	0.3	0.2	2.1	0.8	0.1	0.7	0.8
Macrinite	0.0	0.0	0.0	0.2	0.2	0.0	0.1	0.0
Sclerotinite	0.0	0.1	0.1	0.4	0.1	0.0	0.0	0.1

Sample No.	64	65	66	67	68	69	70	71
Reflectance (%Mean Max. in oil)	6.36	6.40	6.50	6.80	6.01	6.87	6.47	5.83
Vitrinite	44.2	48.3	46.6	42.0	60.1	49.7	48.7	56.3
Psuedo-Vitrinite	14.6	18.7	21.0	29.8	10.5	31.9	12.7	7.1
Resinite	11.5	11.1	6.3	5.3	7.8	4.4	5.6	12.9
Micrinite	3.5	3.8	3.5	3.9	3.8	3.0	3.1	4.4
SemiFusinite	19.5	10.4	13.6	11.9	12.3	6.3	20.2	10.4
Fusinite	2.1	2.1	4.2	2.4	1.8	2.0	3.3	1.4
Sporinite	3.6	4.7	3.9	3.7	2.9	2.1	4.8	5.7
Cutinite	0.9	0.7	0.6	0.6	0.7	0.5	1.5	1.1
Macrinite	0.0	0.1	0.1	0.4	0.0	0.1	0.1	0.4
Sclerotinite	0.1	0.1	0.2	0.0	0.1	0.0	0.0	0.3

Sample No.	72	73	74	75	76	77	78	79
Reflectance (%Mean Max. in oil)	7.23	6.57	5.88	6.50	6.99	6.94	6.17	7.07
Vitrinite	48.8	71.2	61.1	65.0	64.0	51.2	56.0	58.3
Psuedo-Vitrinite	18.9	8.4	24.3	14.4	25.5	21.6	24.0	23.1
Resinite	1.5	2.3	3.3	2.7	0.9	2.2	6.5	2.7
Micrinite	1.8	3.0	3.1	5.6	2.8	6.6	4.3	3.1
SemiFusinite	21.5	8.4	1.6	6.5	1.5	13.7	1.9	7.4
Fusinite	3.0	3.0	0.7	1.7	0.2	2.1	0.4	0.8
Sporinite	3.4	2.9	4.5	3.0	3.8	2.1	4.8	3.5
Cutinite	1.1	0.8	1.1	1.0	1.3	0.4	1.8	1.0
Macrinite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sclerotinite	0.0	0.0	0.3	0.1	0.0	0.1	0.3	0.1

Sample No.	80	81	82	83	85	86	88	89
Reflectance (%Mean Max. in oil)	6.84	6.94	6.90	7.15	7.35	6.84	7.88	7.08
Vitrinite	60.7	57.5	64.8	50.2	53.7	57.1	52.0	71.3
Psuedo-Vitrinite	16.4	17.1	12.6	36.9	18.8	16.1	29.8	17.3
Resinite	5.0	2.3	3.7	2.3	2.8	7.1	3.4	1.1
Micrinite	2.6	2.1	2.7	2.1	3.6	2.2	1.7	2.5
SemiFusinite	8.9	10.9	8.7	3.9	16.1	10.2	6.1	2.4
Fusinite	2.6	3.8	2.2	0.6	2.0	1.8	3.3	0.1
Sporinite	2.1	4.5	4.4	3.3	1.9	1.3	3.0	4.4
Cutinite	1.5	1.7	0.8	0.5	0.9	4.0	0.5	0.9
Macrinite	0.1	0.1	0.0	0.1	0.2	0.2	0.1	0.0
Sclerotinite	0.1	0.0	0.1	0.1	0.0	0.0	0.1	0.0

Sample No.	90	92	93	94	95	97	98	99
Reflectance (%Mean Max. in oil)	6.33	6.94	6.53	6.09	6.13	7.01	6.33	6.74
Vitrinite	64.5	60.9	62.9	69.0	67.4	56.8	52.7	65.5
Psuedo-Vitrinite	21.5	5.2	7.9	17.7	13.5	34.8	23.0	15.6
Resinite	3.4	1.7	16.2	5.2	2.5	2.2	6.4	4.4
Micrinite	1.5	3.2	2.9	3.1	1.7	3.2	2.3	2.7
SemiFusinite	4.7	23.0	6.4	1.8	10.6	0.9	12.3	7.6
Fusinite	0.8	3.1	1.5	0.2	2.0	0.0	1.5	1.6
Sporinite	2.8	2.4	1.5	2.0	1.8	1.4	1.4	2.2
Cutinite	0.7	0.5	0.7	1.0	0.3	0.7	0.2	0.2
Macrinite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Sclerotinite	0.1	0.0	0.0	0.0	0.2	0.0	0.2	0.0

Sample No.	100	101	102	103	108	109	113	114
Reflectance (%Mean Max. in oil)	7.24	6.19	7.21	6.81	6.15	7.03	7.08	7.06
Vitrinite	58.6	58.0	42.8	67.3	60.4	43.4	71.4	70.5
Psuedo-Vitrinite	16.2	9.8	24.4	12.2	28.3	5.9	11.6	12.0
Resinite	1.9	9.5	1.5	1.4	2.3	3.5	1.6	2.7
Micrinite	5.0	3.7	4.4	1.6	2.5	4.0	1.3	1.9
SemiFusinite	14.2	13.3	22.8	13.6	1.5	36.3	8.6	8.7
Fusinite	0.0	2.2	2.4	1.9	0.4	2.2	1.9	1.6
Sporinite	1.9	2.7	1.5	1.5	3.4	3.9	2.3	2.2
Cutinite	0.1	0.7	0.1	0.5	1.2	0.8	1.2	0.4
Macrinite	2.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0
Sclerotinite	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0

Sample No.	162	165	170	179	181	183	184	190
Reflectance (%Mean Max. in oil)	6.31	6.30	6.80	6.75	6.34	5.83	6.34	6.53
Vitrinite	61.9	43.9	61.8	61.2	61.5	54.8	55.1	64.8
Psuedo-Vitrinite	7.3	29.1	8.9	18.4	14.6	18.6	16.2	20.0
Resinite	1.2	1.3	1.9	0.5	6.2	1.2	2.2	0.4
Micrinite	2.7	2.9	3.7	3.3	1.5	1.2	2.4	2.4
SemiFusinite	21.6	12.9	17.4	9.8	10.7	17.0	15.6	6.3
Fusinite	2.9	7.2	2.9	0.0	3.4	4.8	1.7	2.2
Sporinite	2.2	2.1	1.9	2.9	1.9	1.1	5.6	2.4
Cutinite	0.2	0.6	1.5	1.5	0.2	1.3	0.6	1.5
Macrinite	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
Sclerotinite	0.0	0.0	0.0	2.4	0.0	0.0	0.1	0.0

Sample No.	192	193	194	197	198	200	201	204
Reflectance (%Mean Max. in oil)	7.10	6.99	5.70	5.94	6.37	6.33	5.76	6.99
Vitrinite	59.5	49.8	61.9	55.2	59.8	59.8	60.1	46.4
Psuedo-Vitrinite	3.9	4.5	28.3	32.6	27.9	11.4	8.9	25.8
Resinite	3.1	2.0	1.3	0.7	0.6	0.8	1.1	1.6
Micrinite	2.1	2.0	1.5	3.2	2.5	6.7	2.4	3.7
SemiFusinite	27.8	32.9	2.5	3.8	3.7	16.3	13.7	18.1
Fusinite	0.8	3.6	0.6	0.9	0.4	3.1	7.0	2.7
Sporinite	1.8	3.9	1.8	3.0	3.8	1.8	4.8	1.2
Cutinite	0.8	1.3	2.1	0.4	1.3	0.0	2.0	0.1
Macrinite	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.1
Sclerotinite	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.3

Sample No.	205	206	207	208	209	210	212	213
Reflectance (%Mean Max. in oil)	7.22	6.38	5.91	7.09	6.72	6.19	5.57	7.21
Vitrinite	54.8	60.2	57.0	48.9	85.3	43.6	42.6	50.2
Psuedo-Vitrinite	17.9	12.3	22.8	12.4	9.8	17.9	2.1	39.5
Resinite	4.1	0.8	0.4	2.6	4.1	1.1	1.4	2.3
Micrinite	1.2	3.9	3.4	1.4	0.3	5.9	4.3	1.1
SemiFusinite	15.8	16.9	9.9	29.7	0.0	23.7	37.9	4.4
Fusinite	2.7	3.2	2.8	2.8	0.0	4.7	7.0	1.6
Sporinite	1.6	2.0	2.4	1.2	0.5	2.2	4.2	0.9
Cutinite	1.6	0.7	1.3	1.2	0.0	0.8	0.3	0.0
Macrinite	0.3	0.0	0.0	0.1	0.0	0.1	0.1	0.0
Sclerotinite	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0

Sample No.	214	215	217	219	220	221	223	224
Reflectance (%Mean Max. in oil)	6.28	5.91	7.11	5.71	6.89	6.87	6.49	5.69
Vitrinite	74.9	63.7	57.7	64.7	63.4	64.5	55.1	73.4
Psuedo-Vitrinite	12.7	8.0	27.0	3.7	15.4	23.1	3.9	17.1
Resinite	6.9	1.8	2.0	1.0	0.8	2.0	0.3	1.6
Micrinite	1.0	0.9	3.3	4.2	0.3	1.0	1.4	1.7
SemiFusinite	2.2	18.6	1.7	18.8	12.2	5.7	32.6	1.2
Fusinite	0.4	5.1	6.6	5.2	3.8	0.6	2.8	2.4
Sporinite	1.3	1.3	1.6	1.8	2.0	3.0	2.8	2.5
Cutinite	0.6	0.5	0.1	0.4	1.9	0.0	1.0	0.1
Macrinite	0.0	0.1	0.0	0.2	0.1	0.1	0.1	0.0
Sclerotinite	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0

Sample No.	225	226	227	228	229	230	231	232
Reflectance (%Mean Max. in oil)	5.69	5.46	5.73	5.26	6.21	6.51	6.13	5.90
Vitrinite	57.6	61.3	70.1	77.9	46.1	54.8	71.1	68.7
Psuedo-Vitrinite	30.0	32.9	12.5	10.7	16.5	26.5	11.1	18.4
Resinite	6.2	1.1	3.6	1.5	17.8	3.7	4.4	2.5
Micrinite	1.2	2.0	1.3	1.9	4.1	2.1	1.7	0.9
SemiFusinite	3.3	0.9	9.2	1.4	9.2	8.6	6.9	6.4
Fusinite	0.7	0.2	1.8	3.4	1.3	1.1	1.1	0.7
Sporinite	1.0	1.3	1.3	2.9	4.2	1.7	3.1	1.7
Cutinite	0.0	0.3	0.2	0.3	0.6	1.5	0.6	0.6
Macrinite	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1
Sclerotinite	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0

Sample No.	233	235	236	238	239	240	241	242
Reflectance (%Mean Max. in oil)	5.47	6.39	7.05	5.83	5.88	5.90	6.18	2.27
Vitrinite	61.3	64.8	46.5	70.1	71.3	70.2	62.7	60.6
Psuedo-Vitrinite	22.9	10.7	45.8	24.8	15.4	20.9	32.0	32.9
Resinite	0.6	1.3	2.7	0.9	3.3	1.5	2.3	1.8
Micrinite	2.4	1.8	0.9	0.5	2.4	2.0	0.4	1.5
SemiFusinite	9.2	15.3	1.4	0.7	4.3	2.0	1.8	1.5
Fusinite	1.8	1.8	1.0	0.1	0.7	0.6	0.5	0.5
Sporinite	1.4	3.2	0.8	1.5	1.5	2.4	0.2	0.8
Cutinite	0.3	1.0	0.9	1.4	1.0	0.4	0.1	0.4
Macrinite	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.0
Sclerotinite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	243	244	245	246	247	248	249	250
Reflectance (%Mean Max. in oil)	6.10	5.85	7.58	6.51	5.62	5.95	6.77	7.47
Vitrinite	64.1	62.9	51.3	52.9	67.6	50.6	52.1	44.7
Psuedo-Vitrinite	22.9	32.8	40.2	33.0	24.2	19.3	22.5	42.6
Resinite	5.8	0.9	1.9	2.8	2.3	1.8	4.6	0.9
Micrinite	0.6	0.7	1.0	3.5	0.5	2.7	3.6	0.9
SemiFusinite	4.0	0.7	1.3	3.6	2.7	15.2	9.9	6.2
Fusinite	0.9	0.0	0.6	1.0	0.8	3.8	5.7	3.5
Sporinite	1.5	1.5	2.7	1.8	1.7	5.0	1.3	1.2
Cutinite	0.2	0.5	1.0	1.4	0.2	1.6	0.2	0.0
Macrinite	0.6	0.7	1.0	3.5	0.5	2.7	3.6	0.9
Sclerotinite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	251	252	253	254	255	256	257	258
Reflectance (%Mean Max. in oil)	5.64	5.39	5.67	6.82	7.41	7.26	6.95	7.45
Vitrinite	65.8	67.9	61.4	48.7	61.9	50.7	53.6	76.7
Psuedo-Vitrinite	20.7	11.8	14.7	17.3	24.7	33.1	33.7	12.4
Resinite	4.5	2.6	3.3	10.4	2.7	2.5	1.7	1.3
Micrinite	0.4	3.2	5.5	4.7	2.2	3.4	1.4	0.8
SemiFusinite	3.4	5.8	8.9	10.2	5.1	3.8	2.1	5.1
Fusinite	1.2	1.8	3.8	4.1	0.7	3.2	4.1	2.3
Sporinite	2.5	6.1	1.9	2.4	1.5	2.1	2.5	1.2
Cutinite	1.4	0.6	0.5	2.2	0.4	1.0	0.9	0.2
Macrinite	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Sclerotinite	0.1	0.2	0.0	0.0	0.7	0.2	0.0	0.0

Sample No.	260	261	262	264	266	269	270	271
Reflectance (%Mean Max. in oil)	8.14	6.29	8.11	5.63	7.36	5.50	5.38	5.78
Vitrinite	57.3	53.0	53.3	63.3	14.1	67.4	63.5	70.4
Psuedo-Vitrinite	20.9	4.8	23.8	31.8	81.2	67.4	63.5	70.4
Resinite	0.7	1.2	1.2	0.3	1.7	1.5	2.4	4.4
Micrinite	2.7	4.7	2.3	1.5	0.8	5.7	1.6	0.9
SemiFusinite	11.2	16.9	11.3	1.2	1.0	9.0	16.4	3.6
Fusinite	5.9	12.9	4.6	0.6	0.1	6.0	5.4	2.3
Sporinite	0.7	5.0	2.9	1.1	0.8	2.1	3.8	3.8
Cutinite	0.6	1.5	0.3	0.2	0.3	0.5	1.4	0.8
Macrinite	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.0
Sclerotinite	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1

Sample No.	272	276	277	278	279	280	281	282
Reflectance (%Mean Max. in oil)	5.76	5.78	6.34	6.22	5.91	6.21	5.56	6.07
Vitrinite	30.5	49.0	39.7	66.0	41.6	38.3	72.9	70.4
Psuedo-Vitrinite	63.0	30.5	40.1	14.8	33.3	45.1	9.3	16.0
Resinite	1.7	3.0	1.1	2.0	7.4	2.6	2.5	1.5
Micrinite	1.3	1.9	8.3	1.6	3.5	1.4	0.6	2.3
SemiFusinite	0.5	6.2	4.3	8.7	5.9	3.1	6.2	4.2
Fusinite	0.2	2.7	2.6	3.4	4.6	7.2	3.4	2.6
Sporinite	1.1	4.6	1.9	2.9	2.8	1.4	2.4	2.5
Cutinite	1.7	2.1	2.0	0.6	0.9	0.9	1.7	0.5
Macrinite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sclerotinite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	283	284	285	286	287	288	289	290
Reflectance (%Mean Max. in oil)	5.24	5.01	5.91	5.59	5.36	5.83	6.05	5.98
Vitrinite	72.5	57.5	67.9	64.5	81.8	65.1	90.8	48.9
Psuedo-Vitrinite	14.5	13.2	20.9	20.9	11.2	30.2	18.8	11.4
Resinite	2.6	4.3	1.5	1.8	0.2	0.6	1.7	5.2
Micrinite	0.7	4.0	1.0	1.2	0.8	0.6	0.8	3.4
SemiFusinite	5.6	10.7	2.2	5.4	1.1	1.0	1.9	20.2
Fusinite	1.3	4.0	1.3	2.1	0.4	0.2	0.3	2.4
Sporinite	1.9	4.2	3.8	3.9	4.3	2.0	4.1	7.1
Cutinite	0.9	1.6	1.2	0.2	0.1	0.1	0.4	1.2
Macrinite	0.0	0.2	0.0	0.0	0.0	0.0	0.0	3.4
Sclerotinite	0.0	0.3	0.2	0.0	0.1	0.2	0.0	0.0

Sample No.	291	292	293	294	295	296	297	298
Reflectance (%Mean Max. in oil)	4.93	5.03	5.30	5.38	5.45	5.36	5.53	5.34
Vitrinite	42.3	66.7	47.8	50.7	74.4	52.7	58.6	33.1
Psuedo-Vitrinite	41.9	7.8	13.9	28.8	12.5	29.7	27.2	51.1
Resinite	1.9	1.6	28.3	2.7	2.3	10.2	1.4	8.2
Micrinite	1.2	3.9	1.7	0.9	1.5	1.4	1.3	0.6
SemiFusinite	6.6	11.8	5.2	9.1	4.8	2.1	5.7	0.6
Fusinite	3.3	3.6	1.7	5.5	2.4	1.4	4.2	1.9
Sporinite	2.1	3.9	1.1	1.8	1.8	2.0	1.3	2.4
Cutinite	0.7	0.7	0.3	0.5	0.2	0.5	0.1	2.1
Macrinite	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Sclerotinite	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0

Sample No.	299	300	301	302	303	304	305	306
Reflectance (%Mean Max. in oil)	5.90	5.39	5.53	5.43	4.80	5.06	5.77	5.64
Vitrinite	52.5	65.2	51.7	36.9	59.6	50.8	45.6	30.8
Psuedo-Vitrinite	24.3	19.6	18.4	51.3	9.8	8.1	3.2	61.0
Resinite	2.1	2.3	14.5	2.8	11.8	25.7	4.0	1.8
Micrinite	5.8	1.8	4.5	2.9	2.8	1.8	5.9	2.4
SemiFusinite	7.4	2.4	3.9	1.5	7.5	7.4	27.2	0.2
Fusinite	4.3	2.1	3.1	0.9	3.6	2.4	9.2	1.9
Sporinite	3.2	4.8	3.6	2.4	4.4	3.6	4.3	1.5
Cutinite	0.4	1.8	0.1	1.2	0.3	0.1	0.6	0.4
Macrinite	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0
Sclerotinite	0.0	0.0	0.2	0.0	0.1	0.0	0.0	0.0

Sample No.	307	308	309	310	311	312	313	314
Reflectance (%Mean Max. in oil)	5.49	5.13	5.28	5.51	6.72	6.84	6.76	6.51
Vitrinite	63.7	58.9	59.0	56.2	46.6	46.6	39.2	55.5
Psuedo-Vitrinite	22.7	11.8	9.2	15.1	32.8	35.4	48.8	30.2
Resinite	0.7	5.4	2.5	3.0	1.0	0.8	1.0	0.6
Micrinite	2.6	2.6	3.7	3.2	1.4	3.8	0.9	1.4
SemiFusinite	2.7	10.0	15.5	10.0	6.0	6.2	1.8	2.9
Fusinite	0.7	5.3	6.6	10.1	8.9	4.0	5.2	5.8
Sporinite	6.6	5.5	2.9	2.1	3.0	2.9	2.7	3.0
Cutinite	0.1	0.4	0.4	0.1	0.2	0.1	0.3	0.3
Macrinite	0.0	0.0	0.2	0.0	0.1	0.1	0.0	0.3
Sclerotinite	0.2	0.1	0.0	0.2	0.0	0.1	0.1	0.0

Sample No.	315	316
Reflectance (%Mean Max. in oil)	6.56	5.20
Vitrinite	59.8	58.0
Psuedo-Vitrinite	12.7	23.4
Resinite	0.6	5.3
Micrinite	3.8	1.0
SemiFusinite	7.1	3.1
Fusinite	13.4	5.7
Sporinite	2.4	2.8
Cutinite	0.2	0.7
Macrinite	0.0	0.0
Sclerotinite	0.0	0.0

Fluorescent Maceral Analysis - This analysis was run on a Leitz Ortholux II microscope at 500X magnification. A 100 watt mercury lamp with a BG23 filter and a BG12 blue light filter were used. The light was passed to a vertical illuminator adapted with a TK 400 mirror. Light to the occulars was filtered through a K510 barrier filter.

The fluorescent maceral composition of the samples is contained in the following table:

FLUORESCENCE MACERAL ANALYSIS

Sample No.	1	2	5	8	9	10	11	12
Non Flrscnc	84.0	89.6	86.9	94.6	93.0	90.6	91.2	91.7
Green	2.9	3.4	2.5	1.5	1.1	0.7	2.6	1.4
Yellow	0.4	0.4	0.4	0.5	0.2	0.3	0.4	0.4
Orange	1.5	0.9	2.2	0.3	1.0	0.7	1.6	0.8
Exudatinite	0.1	0.2	0.2	0.2	0.3	0.2	0.4	0.2
Cutinite	2.2	1.3	2.1	1.6	1.0	1.2	1.4	2.2
Sporinite	8.4	3.9	5.5	1.1	3.0	3.7	2.4	3.2
Bituminite	0.5	0.3	0.2	0.0	0.4	2.4	0.0	0.1
Fluorinite	0.0	0.0	0.0	0.2	0.0	0.2	0.0	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	13	14	15	16	17	18	19	20
Non Flrscnc	93.6	94.5	93.3	90.6	91.5	90.1	87.9	89.9
Green	0.7	0.9	1.3	1.1	0.5	1.8	1.9	4.9
Yellow	1.1	0.3	0.4	0.4	0.4	0.2	0.2	0.3
Orange	1.0	1.0	0.6	0.2	0.6	1.7	1.0	1.0
Exudatinite	0.2	0.3	0.2	0.2	0.1	0.0	0.0	0.2
Cutinite	1.0	1.3	1.4	4.1	3.2	1.5	1.5	1.3
Sporinite	2.4	1.7	2.7	3.0	3.7	4.7	7.3	2.4
Bituminite	0.0	0.0	0.1	0.1	0.0	0.0	0.2	0.0
Fluorinite	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Alginite	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0

Sample No.	21	22	23	24	25	27	31	33
Non Flrscnc	94.9	96.3	97.1	89.0	91.1	96.1	94.7	91.9
Green	0.9	0.9	1.3	3.3	1.1	2.2	0.6	0.8
Yellow	0.6	0.9	0.0	0.2	0.7	0.1	0.6	0.1
Orange	0.9	0.6	0.3	0.8	0.3	0.3	0.1	0.5
Exudatinite	0.5	0.2	0.1	1.1	0.5	0.1	0.0	0.0
Cutinite	0.8	0.3	0.2	2.1	0.8	0.1	0.7	0.8
Sporinite	1.4	1.4	1.0	3.5	5.5	1.1	3.3	5.8
Bituminite	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1
Fluorinite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	64	65	66	67	68	69	70	71
Non Flrscnc	84.0	83.5	89.2	90.4	88.6	93.1	88.1	80.3
Green	7.9	6.6	3.8	2.7	6.4	2.2	2.6	9.0
Yellow	0.8	1.5	0.6	0.9	0.3	0.5	0.4	0.8
Orange	1.4	1.8	1.1	1.2	0.8	0.9	1.7	2.3
Exudatinite	1.4	1.1	0.8	0.5	0.3	0.5	0.9	0.7
Cutinite	0.9	0.7	0.6	0.6	0.7	0.5	1.5	1.1
Sporinite	3.6	4.7	3.9	3.7	2.9	2.1	1.5	1.1
Bituminite	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.1
Fluorinite	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	72	73	74	75	76	77	78	79
Non Flrscnc	93.8	94.0	91.1	93.3	94.0	95.3	86.9	92.7
Green	0.7	0.7	1.9	1.4	0.1	1.2	3.6	0.4
Yellow	0.5	0.1	0.2	0.6	0.2	0.3	0.7	0.4
Orange	0.2	0.5	1.1	0.7	0.4	0.4	1.8	1.3
Exudatinite	0.3	0.9	0.1	0.0	0.2	0.2	0.4	0.3
Cutinite	1.1	0.8	1.1	1.0	1.3	0.4	1.8	1.0
Sporinite	3.4	2.9	4.5	3.0	3.8	2.1	4.8	3.5
Bituminite	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.3
Fluorinite	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	80	81	82	83	85	86	88	89
Non Flrscnc	91.4	91.5	91.1	93.9	94.4	87.6	93.1	93.6
Green	0.5	0.5	1.0	0.9	1.8	5.2	0.0	0.3
Yellow	0.3	0.3	0.2	0.1	0.3	0.3	0.8	0.1
Orange	3.5	0.6	1.7	1.1	0.1	1.3	1.7	0.4
Exudatinite	0.7	0.6	0.7	0.2	0.5	0.3	0.8	0.1
Cutinite	1.5	1.7	0.8	0.5	0.9	1.3	0.5	0.9
Sporinite	2.1	4.5	4.4	3.3	1.9	4.0	3.0	4.4
Bituminite	0.0	0.3	0.1	0.0	0.1	0.0	0.1	0.2
Fluorinite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	90	92	93	94	95	97	98	99
Non Flrscnc	93.1	95.4	81.6	91.8	95.4	95.7	92.0	93.2
Green	0.9	1.4	13.7	3.3	1.1	1.3	5.1	3.7
Yellow	0.3	0.1	0.3	0.7	0.2	0.3	0.1	0.5
Orange	2.1	0.0	1.4	0.9	0.9	0.2	0.9	0.1
Exudatinite	0.0	0.1	0.8	0.3	0.3	0.4	0.3	0.1
Cutinite	0.7	0.5	0.7	1.0	0.3	0.7	0.2	0.2
Sporinite	2.8	2.4	1.5	2.0	1.8	1.4	1.4	2.2
Bituminite	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fluorinite	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	100	101	102	103	108	109	113	114
Non Flrscnc	96.1	87.1	96.9	96.6	93.1	91.8	95.0	94.7
Green	0.5	6.8	0.5	0.9	0.0	2.2	0.5	0.6
Yellow	0.5	0.4	0.5	0.3	0.4	0.1	0.2	0.4
Orange	0.8	1.9	0.5	0.2	1.4	0.9	0.5	1.6
Exudatinite	0.0	0.4	0.0	0.0	0.3	0.3	0.1	0.1
Cutinite	0.1	0.7	0.1	0.5	1.2	0.8	1.2	0.4
Sporinite	1.9	2.7	1.5	1.5	3.4	3.9	2.3	2.2
Bituminite	0.1	0.0	0.0	0.0	0.2	0.0	0.3	0.0
Fluorinite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	162	165	170	179	181	183	184	190
Non Flrscnc	96.4	96.0	94.7	95.1	91.7	96.4	91.6	95.7
Green	0.4	1.0	0.5	0.1	1.3	0.2	0.0	0.4
Yellow	0.3	0.2	0.5	0.1	2.4	0.1	1.8	0.0
Orange	0.3	0.1	0.4	0.3	1.7	0.4	0.4	0.0
Exudatinite	0.2	0.0	0.4	0.0	0.8	0.3	0.0	0.0
Cutinite	0.2	0.6	1.5	1.5	0.2	1.3	0.6	1.5
Sporinite	2.2	2.1	1.9	2.9	1.9	1.1	5.6	2.4
Bituminite	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Fluorinite	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	192	193	194	197	198	200	201	204
Non Flrscnc	94.3	92.8	94.8	95.9	94.3	97.4	92.1	97.1
Green	2.7	0.7	0.2	0.5	0.4	0.7	0.3	0.9
Yellow	0.1	0.5	0.8	0.0	0.0	0.0	0.0	0.0
Orange	0.3	0.6	0.2	0.1	0.1	0.1	0.7	0.6
Exudatinite	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.1
Cutinite	0.8	1.3	2.1	0.4	1.3	0.0	2.0	0.1
Sporinite	1.8	3.9	1.8	3.0	3.8	1.8	4.8	1.2
Bituminite	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Fluorinite	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	205	206	207	208	209	210	212	213
Non Flrscnc	92.7	96.5	95.9	95.3	95.4	95.9	94.1	96.8
Green	3.6	0.2	0.3	0.5	0.0	0.5	1.2	2.1
Yellow	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.0
Orange	0.3	0.6	0.1	1.6	3.7	0.1	0.2	0.2
Exudatinite	0.2	0.0	0.0	0.5	0.0	0.0	0.0	0.0
Cutinite	1.6	0.7	1.3	0.9	0.0	0.8	0.3	0.0
Sporinite	1.6	2.0	2.4	1.2	0.5	2.2	4.2	0.9
Bituminite	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Fluorinite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	214	215	217	219	220	221	223	224
Non Flrscnc	91.2	96.4	96.3	96.8	95.3	95.0	95.9	95.8
Green	0.1	1.0	0.4	1.0	0.5	1.2	0.1	0.7
Yellow	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Orange	6.7	0.6	1.0	0.0	0.3	0.6	0.2	0.3
Exudatinite	0.0	0.1	0.6	0.0	0.0	0.0	0.0	0.4
Cutinite	0.6	0.5	0.1	0.4	1.9	0.0	1.0	0.1
Sporinite	1.3	1.3	1.6	1.8	2.0	3.0	2.8	2.5
Bituminite	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2
Fluorinite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	225	226	227	228	229	230	231	232
Non Flrscnc	92.8	97.3	94.9	95.3	77.3	93.1	91.9	95.2
Green	6.1	0.4	3.5	0.5	16.4	0.4	3.5	2.3
Yellow	0.0	0.0	0.0	0.0	0.4	0.4	0.2	0.1
Orange	0.1	0.2	0.1	0.6	0.7	1.9	0.4	0.1
Exudatinite	0.0	0.1	0.0	0.1	0.2	0.9	0.2	0.0
Cutinite	0.0	0.3	0.2	0.3	0.6	1.5	0.6	0.6
Sporinite	1.0	1.3	1.3	2.9	4.2	1.7	3.1	1.7
Bituminite	0.0	0.4	0.0	0.3	0.1	0.1	0.1	0.0
Fluorinite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	233	235	236	238	239	240	241	242
Non Flrscnc	97.7	94.5	95.6	96.2	94.2	95.7	97.4	97.0
Green	0.4	0.3	2.7	0.6	2.0	0.8	2.1	1.3
Yellow	0.0	0.2	0.0	0.0	0.2	0.2	0.1	0.2
Orange	0.2	0.7	0.0	0.1	0.7	0.3	0.0	0.1
Exudatinite	0.0	0.1	0.0	0.1	0.3	0.2	0.0	0.0
Cutinite	0.3	1.0	0.9	1.4	1.0	0.4	0.1	0.4
Sporinite	1.4	3.2	0.8	1.5	1.5	2.4	0.2	0.8
Bituminite	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.2
Fluorinite	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	243	244	245	246	247	248	249	250
Non Flrscnc	92.5	97.2	94.4	94.0	95.8	91.6	93.9	97.9
Green	5.2	0.7	1.7	1.6	1.9	1.5	1.2	0.6
Yellow	0.5	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Orange	0.1	0.1	0.2	1.0	0.4	0.2	2.7	0.3
Exudatinite	0.0	0.0	0.0	0.0	0.0	0.1	0.7	0.0
Cutinite	0.2	0.5	1.0	1.4	0.2	1.6	0.2	0.0
Sporinite	1.5	1.5	2.7	1.8	1.7	5.0	1.3	1.2
Bituminite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fluorinite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	251	252	253	254	255	256	257	258
Non Flrscnc	91.6	90.7	94.3	85.0	95.4	94.4	94.9	97.3
Green	4.3	2.0	2.8	8.2	2.4	2.1	0.6	0.0
Yellow	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
Orange	0.1	0.5	0.5	1.2	0.3	0.3	0.9	1.2
Exudatinite	0.0	0.1	0.0	0.7	0.0	0.1	0.2	0.1
Cutinite	1.4	0.6	0.5	2.2	0.4	1.0	0.9	0.2
Sporinite	2.5	6.1	1.9	2.4	1.5	2.1	2.5	1.2
Bituminite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fluorinite	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	260	261	262	264	266	269	270	271
Non Flrscnc	98.0	92.3	95.6	98.4	97.2	95.9	92.4	91.0
Green	0.0	0.6	0.4	0.0	1.2	1.4	1.7	3.5
Yellow	0.1	0.0	0.1	0.0	0.0	0.0	0.3	0.1
Orange	0.6	0.3	0.7	0.3	0.3	0.1	0.3	0.6
Exudatinite	0.0	0.3	0.0	0.0	0.0	0.0	0.1	0.2
Cutinite	0.6	1.5	0.3	0.2	0.3	0.5	1.4	0.8
Sporinite	0.7	5.0	2.9	1.1	0.8	2.1	3.8	3.8
Bituminite	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Fluorinite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	272	276	277	278	279	280	281	283
Non Flrscnc	95.5	90.3	95.0	94.5	88.9	95.1	93.4	95.4
Green	1.2	2.7	0.4	1.5	6.1	2.2	2.2	0.6
Yellow	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.1
Orange	0.5	0.1	0.4	0.2	0.3	0.0	0.1	0.4
Exudatinite	0.0	0.2	0.1	0.2	0.9	0.3	0.1	0.0
Cutinite	1.7	2.1	2.0	0.6	0.9	0.9	1.7	0.4
Sporinite	1.1	4.6	1.9	2.9	2.8	1.4	2.4	3.1
Bituminite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fluorinite	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	284	285	286	287	288	289	290	291
Non Flrscnc	87.9	94.1	94.4	94.8	98.0	92.5	86.5	95.3
Green	4.4	0.6	2.6	0.1	0.2	1.1	3.6	1.1
Yellow	0.2	0.1	0.0	0.0	0.0	0.3	0.0	0.2
Orange	0.5	0.5	0.1	0.0	0.1	0.8	1.2	0.5
Exudatinite	0.6	0.2	0.1	0.1	0.0	0.1	0.1	0.1
Cutinite	1.6	1.5	0.2	0.3	0.0	0.3	1.2	0.7
Sporinite	4.5	3.0	2.6	4.7	1.7	4.9	7.1	2.1
Bituminite	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Fluorinite	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	292	293	294	295	296	297	298	299
Non Flrscnc	93.8	70.3	95.0	95.7	87.3	97.2	87.3	94.3
Green	1.1	27.6	2.5	2.0	9.7	0.9	7.3	1.4
Yellow	0.1	0.2	0.1	0.0	0.1	0.0	0.0	0.1
Orange	0.2	0.3	0.0	0.2	0.4	0.2	0.4	0.5
Exudatinite	0.2	0.2	0.1	0.1	0.0	0.0	0.5	0.1
Cutinite	0.7	0.3	0.5	0.2	0.5	0.1	2.1	0.4
Sporinite	3.9	1.1	1.8	1.8	2.0	1.3	2.4	3.2
Bituminite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fluorinite	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	300	301	302	303	304	305	306	307
Non Flrscnc	91.1	81.8	93.6	83.5	70.6	91.1	96.3	92.6
Green	1.8	13.8	2.7	9.9	23.2	2.9	1.2	0.6
Yellow	0.2	0.0	0.0	0.3	0.1	0.0	0.1	0.0
Orange	0.3	0.6	0.0	0.6	1.6	1.0	0.2	0.1
Exudatinite	0.0	0.1	0.1	1.0	0.8	0.1	0.2	0.0
Cutinite	1.8	0.1	1.2	0.3	0.1	0.6	0.4	0.1
Sporinite	4.8	3.6	2.4	4.4	3.6	4.3	1.5	6.6
Bituminite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fluorinite	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	308	309	310	311	312	313	314	315
Non Flrscnc	88.7	94.2	94.8	95.8	96.2	96.0	96.1	96.8
Green	4.8	1.7	0.8	0.3	0.5	0.1	0.2	0.2
Yellow	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Orange	0.4	0.7	0.2	0.7	0.3	0.7	0.3	0.3
Exudatinite	0.0	0.1	2.0	0.0	0.0	0.2	0.1	0.0
Cutinite	0.4	0.4	0.1	0.2	0.1	0.3	0.3	0.7
Sporinite	5.5	2.9	2.1	3.0	2.9	2.7	3.0	2.4
Bituminite	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fluorinite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alginite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample No.	316
Non Flrscnc	91.2
Green	3.9
Yellow	0.0
Orange	0.6
Exudatinite	0.8
Cutinite	0.7
Sporinite	2.8
Bituminite	0.0
Fluorinite	0.0
Alginite	0.0

CHEMICAL ANALYSES

Long Proximate Analysis - This analysis includes determination of moisture, ash, volatile matter, fixed carbon, BTU, and sulfur forms and was conducted on all samples except those that were required to be returned to the donor. Sixty five (65) samples from previous work are included. The values recorded in the following table are on an "As Received Basis"; also, the coal samples have been ranked in accordance with the standard specified in ASTM D388-77.

As Received Proximate Analysis, Gas Content, and Rank

Sample No.	1	2	5	8	9	10
As Received						
M	2.54	14.24	10.90	3.19	3.99	3.07
A	14.97	8.20	9.47	5.80	7.71	10.94
VM	40.16	38.34	38.21	39.17	36.00	36.11
FC	42.33	39.22	41.42	51.84	52.30	49.88
S	0.64	0.48	0.57	0.66	0.94	0.86
Gas Content (cm^3/gm)	0.18	1.33	0.06	4.76	5.39	2.77
As Received Btu	11,978	10,428	10,649	13,139	12,872	12,259
Moist M/m-free Btu	14,310	11,448	11,872	14,036	14,069	13,927
ASTM Rank	hvAb	hvCb	hvCb	hvAb	hvAb	hvBb

Sample No.	13	14	15	16	17	18
As Received						
M	3.75	3.03	3.53	4.59	4.23	4.80
A	3.21	3.50	2.58	3.92	7.12	6.11
VM	39.22	38.56	39.76	40.50	38.55	43.89
FC	53.82	54.91	54.13	50.99	50.10	45.20
S	0.71	0.49	0.45	0.68	1.04	0.81
Gas Content (cm^3/gm)	1.69	3.69	4.04	3.36	0.87	1.65
As Received Btu	13,932	13,965	14,064	13,818	13,284	13,044
Moist M/m-free Btu	14,454	14,529	14,481	14,450	14,424	13,989
ASTM Rank	hvAb	hvAb	hvAb	hvAb	hvAb	hvBb

Sample No.	19	20	21	22	23	24
As Received						
M	3.87	4.00	2.09	2.39	3.00	1.88
A	6.01	4.12	5.55	7.72	3.96	8.26
VM	44.71	44.23	37.47	43.93	41.45	45.47
FC	45.41	47.65	54.89	45.96	51.59	44.29
S	0.63	0.53	0.34	0.86	0.60	0.66
Gas Content (cm^3/gm)	0.26	0.45	0.70	1.17	1.12	1.26
As Received Btu	13,086	13,337	10,728	12,998	13,121	13,121
Moist M/m-free Btu	14,013	13,973	11,417	14.207	13,723	14,427
ASTM Rank	hvAb	hvBb	hvCb	hvAb	hvBb	hvAb

Sample No.	25	27	31	33	64	65
As Received						
M	2.03	2.16	1.90	5.05	3.20	2.90
A	7.41	5.56	4.10	9.77	3.50	5.20
VM	42.62	44.16	40.66	42.49	43.20	41.40
FC	47.94	48.12	53.34	42.69	50.10	50.50
S	0.36	0.44	0.57	0.59	0.40	0.40
Gas Content (cm^3/gm)	1.35	2.13	10.94	0.27	1.31	1.40
As Received Btu	12,824	13,193	13,559	12,057	13,394	13,118
Moist M/m-free Btu	13,950	14.049	14,204	13,495	13,931	13,910
ASTM Rank	hvBb	hvAb	hvAb	hvBb	hvBb	hvBb

Sample No.	66	67	68	69	70	71
As Received						
M	3.10	2.60	2.60	2.90	2.70	2.50
A	3.00	6.50	5.90	4.50	6.00	4.90
VM	44.30	42.20	44.20	44.70	40.90	43.10
FC	49.60	48.70	47.30	47.90	50.40	49.50
S	0.60	0.50	0.30	0.50	0.50	0.50
Gas Content (cm^3/gm)	2.59	2.23	0.10	1.66	1.10	2.13
As Received Btu	13,586	13,155	13,276	13,167	12,951	13,284
Moist M/m-free Btu	14,058	14,163	14,189	13,853	13,862	14,041
ASTM Rank	hvAb	hvAb	hvAb	hvBb	hvBb	hvAb

Sample No.	72	73	74	75	76	77
As Received						
M	1.50	1.20	2.80	4.70	1.40	1.80
A	5.50	5.50	6.80	4.70	6.10	4.00
VM	38.40	45.00	47.50	41.50	42.50	41.90
FC	54.50	48.30	42.90	49.10	50.00	50.00
S	0.40	0.30	0.60	0.30	1.30	0.40
Gas Content (cm^3/gm)	8.93	9.40	0.72	0.67	2.20	1.02
As Received Btu	13,550	13,761	13,150	12,912	13,757	13,080
Moist M/m-free Btu	14,418	14,640	14,211	13,610	14,771	13,681
ASTM Rank	hvAb	hvAb	hvAb	hvBb	hvAb	hvBb

Sample No.	78	79	80	81	82	83
As Received						
M	2.60	1.60	1.70	1.70	1.20	1.80
A	8.90	4.40	6.00	7.80	5.90	5.30
VM	44.90	40.20	45.10	43.70	45.60	46.90
FC	43.60	53.80	47.20	46.80	47.30	46.00
S	0.50	0.50	0.50	0.60	0.60	0.50
Gas Content (cm^3/gm)	0.93	5.57	3.90	7.15	8.25	8.43
As Received Btu	12,720	13,749	13,532	13,239	13,900	13,864
Moist M/m-free Btu	14,088	14,450	14,485	14476	14,866	14,722
ASTM Rank	hvAb	hvAb	hvAb	hvAb	hvAb	hvAb

Sample No.	85	86	89	90	92	93
As Received						
M	4.00	1.90	1.50	1.70	4.10	3.20
A	6.90	6.50	20.80	5.70	6.00	3.80
VM	40.80	45.60	38.60	45.70	39.60	45.10
FC	48.30	46.00	39.10	46.90	50.30	47.90
S	0.30	0.40	0.90	0.60	0.40	0.40
Gas Content (cm^3/gm)	1.24	1.50	7.40	2.35	1.75	1.03
As Received Btu	12,441	13,553	11,520	13,792	12756	13,446
Moist M/m-free Btu	13,451	14,589	14,895	14,717	13,651	14,033
ASTM Rank	hvBb	hvAb	hvAb	hvAb	hvBb	hvAb

Sample No.	94	97	98	99	100	101
As Received						
M	2.70	2.50	3.40	3.70	3.00	2.20
A	4.30	7.70	7.10	4.90	5.10	8.40
VM	46.40	44.40	43.20	42.50	39.80	46.70
FC	46.60	45.40	46.30	48.90	52.10	42.70
S	0.40	0.40	0.70	0.40	0.30	0.40
Gas Content (cm^3/gm)	3.00	1.91	1.40	1.26	2.74	2.95
As Received Btu	13,479	12,812	12,884	13,108	12,969	13,143
Moist M/m-free Btu	14,147	13,986	13,974	13,851	13,733	14.642
ASTM Rank	hvAb	hvBb	hvBb	hvBb	hvBb	hvAb

Sample No.	102	103	108	109	113	114
As Received						
M	2.30	2.20	2.10	2.40	2.00	1.70
A	5.20	6.80	8.80	6.00	7.20	5.90
VM	43.30	44.00	46.30	42.60	40.90	45.10
FC	49.20	47.00	42.80	49.00	49.90	47.10
S	0.60	0.40	0.70	0.70	0.70	0.50
Gas Content (cm^3/gm)	1.50	2.30	2.20	2.64	11.02	10.63
As Received Btu	13,586	13,243	13,085	13,278	13,346	13,694
Moist M/m-free Btu	14,413	14,305	14,482	14,219	14,494	14,642
ASTM Rank	hvAb	hvAb	hvAb	hvAb	hvAb	hvAb

Sample No.	162	165	166	167	168	169
As Received						
M	1.80	4.09	*	*	5.40	*
A	10.90	16.95	*	*	4.02	*
VM	40.20	35.88	*	*	39.48	*
FC	47.10	43.08	*	*	51.10	*
S	0.40	2.87	*	*	1.21	*
Gas Content (cm^3/gm)	2.68	0.0	*	*	0.00	*
As Received Btu	12,797	11,217	*	*	12,958	*
Moist M/m-free Btu	14,540	13,821	*	*	13,577	*
ASTM Rank	hvAb	hvBb	*	*	hvBb	*

Sample No.	170	171	172	173	174	175
As Received						
M	2.54	*	3.37	*	*	*
A	8.91	*	7.61	*	*	*
VM	39.56	*	40.83	*	*	*
FC	48.99	*	48.19	*	*	*
S	0.56	*	1.65	*	*	*
Gas Content (cm^3/gm)	0.00	*	0.00	*	*	*
As Received Btu	13,065	*	12,844	*	*	*
Moist M/m-free Btu	14,474	*	14,043	*	*	*
ASTM Rank	hvAb	*	hvAb	*	*	*

Sample No.	176	177	178	179	180	181
As Received						
M	*	*	3.14	3.51	3.28	3.25
A	*	*	14.37	13.81	7.22	19.50
VM	*	*	38.66	37.07	41.02	34.35
FC	*	*	43.83	45.61	48.48	42.90
S	*	*	2.75	0.79	2.40	0.83
Gas Content (cm^3/gm)	*	*	0.10	0.10	0.00	0.00
As Received Btu	*	*	11,743	12,043	12884	11,041
Moist M/m-free Btu	*	*	13,988	14,180	14,045	14,015
ASTM Rank	*	*	hvBb	hvAb	hvAb	hvAb

Sample No.	182	183	184	185	186	187
As Received						
M	*	3.32	3.00	4.78	*	3.58
A	*	10.55	15.30	3.74	*	18.61
VM	*	41.60	38.96	41.82	*	35.38
FC	*	44.53	42.74	49.66	*	42.42
S	*	0.90	1.92	1.31	*	1.69
Gas Content (cm^3/gm)	*	0.40	0.50	1.00	*	0.20
As Received Btu	*	12,474	11,569	13,178	*	10,857
Moist M/m-free Btu	*	14,106	13,920	13,768	*	13,641
ASTM Rank	*	hvAb	hvBb	hvBb	*	hvBb

Sample No.	188	189	190	191	192	193
As Received						
M	*	*	5.57	6.76	5.63	2.65
A	*	*	7.79	12.62	12.13	5.13
VM	*	*	38.21	33.21	35.79	41.97
FC	*	*	48.43	47.41	46.45	50.25
S	*	*	0.72	0.28	0.70	1.15
Gas Content (cm^3/gm)	*	*	0.00	0.00	0.00	0.00
As Received Btu	*	*	12,602	11,570	11,764	13,529
Moist M/m-free Btu	*	*	13,780	13,403	13,557	14,358
ASTM Rank	*	*	hvBb	hvBb	hvBb	hvAb

Sample No.	194	195	196	197	198	199
As Received						
M	3.17	*	*	2.87	2.87	*
A	9.13	*	*	39.90	13.40	*
VM	36.21	*	*	29.21	38.43	*
FC	51.49	*	*	28.02	44.64	*
S	0.76	*	*	0.78	3.15	*
Gas Content (cm^3/gm)	0.00	*	*	0.10	0.40	*
As Received Btu	12,607	*	*	7,768	11,902	*
Moist M/m-free Btu	14,009	*	*	13,658	14,016	*
ASTM Rank	hvAb	*	*	hvBb	hvAb	*

Sample No.	200	201	202	203	204	205
As Received						
M	8.27	2.99	7.35	11.28	4.32	5.63
A	5.69	8.74	23.50	7.32	9.88	12.98
VM	37.44	40.21	34.49	37.32	35.63	34.97
FC	48.60	48.06	34.66	44.08	50.17	46.42
S	0.29	1.46	0.72	0.67	0.67	1.33
Gas Content (cm^3/gm)	0.10	0.40	0.00	0.00	0.00	0.00
As Received Btu	12,034	12,951	9,443	11,221	12,100	11,920
Moist M/m-free Btu	12,828	14,347	12,674	12,197	13,564	13,904
ASTM Rank	hvCb	hvAb	hvCb	hvCb	hvBb	hvBb

Sample No.	206	207	208	209	210	211
As Received						
M	4.43	2.84	4.30	3.16	3.76	6.32
A	7.23	17.26	4.70	9.24	6.35	25.09
VM	38.82	39.20	40.72	39.00	39.40	33.10
FC	49.52	40.70	50.28	48.60	50.49	35.49
S	2.14	6.58	0.81	1.02	0.90	0.52
Gas Content (cm^3/gm)	0.30	0.20	0.20	2.60	1.10	0.00
As Received Btu	12,765	11,430	13,020	12,625	12,998	9,543
Moist M/m-free Btu	13,908	13,280	13,738	14,049	13,981	13,106
ASTM Rank	hvBb	hvBb	hvBb	hvAb	hvBb	hvBb

Sample No.	212	213	214	215	216	217
As Received						
M	7.42	5.02	1.93	2.66	8.07	2.80
A	8.26	10.20	6.27	6.89	13.91	29.33
VM	36.22	34.25	43.91	37.93	35.76	33.10
FC	48.10	50.53	47.89	47.52	42.26	35.49
S	0.63	0.66	0.74	0.31	0.65	0.65
Gas Content (cm^3/gm)	0.00	0.30	1.00	0.20	0.00	0.00
As Received Btu	11,847	11,764	13,342	11,987	10,865	9,504
Moist M/m-free Btu	13,022	13,237	14,334	12,958	12,801	13,936
ASTM Rank	hvBb	hvBb	hvAb	hvCb	hvCb	hvBb

Sample No.	218	219	220	221	222	223
As Received						
M	10.78	8.52	4.50	3.19	10.18	3.26
A	6.13	5.07	8.12	19.93	7.06	15.11
VM	37.33	37.50	37.30	34.99	37.90	38.72
FC	45.76	48.91	50.08	41.89	44.86	42.91
S	0.46	0.35	0.53	3.36	1.04	7.33
Gas Content (cm^3/gm)	0.10	0.40	0.30	0.00	0.20	0.00
As Received Btu	11,674	12,080	12,480	10,911	11,581	11,502
Moist M/m-free Btu	12,511	12,787	13,694	14,020	12,558	13,981
ASTM Rank	hvCb	hvCb	hvBb	hvAb	hvCb	hvBb

Sample No.	224	225	226	227	228	229
As Received						
M	6.77	8.49	5.66	5.83	8.46	2.20
A	7.08	3.51	5.05	7.83	6.91	16.26
VM	41.12	42.20	43.49	41.28	40.11	35.80
FC	45.03	45.80	45.80	45.06	44.52	45.74
S	0.65	0.50	0.93	0.81	1.06	0.54
Gas Content (cm^3/gm)	0.00	0.10	0.00	0.00	0.00	1.60
As Received Btu	12,230	12,555	12,818	12,323	11,705	11,678
Moist M/m-free Btu	13,259	13,061	13,582	13,483	12,672	14,184
ASTM Rank	hvBb	hvBb	hvBb	hvBb	hvCb	hvAb

Sample No.	230	231	232	233	234	235
As Received						
M	3.44	8.37	7.72	6.97	8.14	4.84
A	27.23	2.30	9.40	8.15	6.71	4.07
VM	28.65	39.25	38.20	38.53	42.74	40.84
FC	40.68	50.08	44.68	46.35	42.41	50.25
S	0.37	0.47	0.55	0.62	0.76	0.63
Gas Content (cm^3/gm)	1.10	0.60	0.20	0.30	0.40	0.60
As Received Btu	9,895	12,614	11,682	11,921	12,041	13,126
Moist M/m-free Btu	14,031	12,946	13,015	13,086	12,999	13,746
ASTM Rank	hvAb	hvCb	hvBb	hvBb	hvCb	hvBb

Sample No.	236	237	238	239	240	241
As Received						
M	5.89	2.90	8.05	5.18	7.01	9.32
A	9.14	3.61	30.03	14.13	3.64	2.13
VM	36.31	40.70	31.47	41.82	44.64	43.38
FC	48.66	52.79	30.45	38.87	44.64	45.17
S	0.57	0.54	0.63	1.52	0.39	0.56
Gas Content (cm^3/gm)	0.40	4.80	0.00	0.30	0.20	0.80
As Received Btu	12,404	13,621	8,511	11,489	12,778	12,391
Moist M/m-free Btu	13,779	14,189	12,614	13,603	13,310	12,694
ASTM Rank	hvBb	hvAb	hvCb	hvBb	hvBb	hvCb

Sample No.	242	243	244	245	246	247
As Received						
M	7.37	6.46	6.83	7.61	2.82	6.00
A	3.00	2.70	4.84	3.10	4.24	4.79
VM	43.68	45.08	44.07	40.10	42.29	44.86
FC	45.95	45.76	44.26	49.19	50.65	44.35
S	0.47	0.41	0.53	0.68	0.79	0.35
Gas Content (cm^3/gm)	0.10	0.30	0.40	0.40	2.30	0.20
As Received Btu	13,175	13,301	13,253	13,489	14,214	12,821
Moist M/m-free Btu	13,175	13,301	13,253	13,489	14,214	13,529
ASTM Rank	hvBb	hvBb	hvBb	hvBb	hvAb	hvBb

Sample No.	248	249	250	251	252	253
As Received						
M	4.68	4.15	5.69	4.99	4.91	7.13
A	8.17	9.29	2.45	5.27	7.38	8.71
VM	41.15	35.55	39.73	45.45	44.59	38.53
FC	46.00	51.01	52.13	44.29	43.12	45.63
S	0.87	0.48	0.60	0.48	0.47	0.46
Gas Content (cm^3/gm)	0.80	0.50	0.30	0.40	1.80	0.30
As Received Btu	12,606	12,525	12,957	12,818	12,375	12,315
Moist M/m-free Btu	13,851	13,936	13,324	13,604	13,459	13,606
ASTM Rank	hvBb	hvBb	hvBb	hvBb	hvBb	hvBb

Sample No.	254	255	256	257	258	259
As Received						
M	2.62	3.27	6.77	3.84	1.95	5.91
A	9.82	13.19	11.96	17.97	9.64	6.48
VM	41.27	38.76	35.90	37.82	43.18	44.62
FC	46.29	44.78	45.37	40.37	45.23	42.99
S	0.53	0.62	0.54	0.75	0.83	0.54
Gas Content (cm^3/gm)	2.80	6.60	0.90	2.00	1.80	2.00
As Received Btu	12,742	11,951	11,847	10,948	13,160	12,540
Moist M/m-free Btu	14,271	13,500	13,620	13,608	14,718	13,498
ASTM Rank	hvAb	hvBb	hvBb	hvBb	hvAb	hvBb

Sample No.	260	261	262	263	264	265
As Received						
M	2.07	2.59	2.50	8.17	3.71	3.21
A	11.69	4.46	5.01	3.19	14.06	5.71
VM	35.34	40.67	37.30	41.29	40.34	43.81
FC	50.90	52.28	55.19	47.35	41.89	47.27
S	0.42	0.91	0.48	0.52	2.46	1.10
Gas Content (cm^3/gm)	9.40	5.30	6.60	1.30	4.70	1.50
As Received Btu	12,633	13,094	13,607	12,664	11,697	13,319
Moist M/m-free Btu	14,473	13,781	14,400	13,128	13,867	14,227
ASTM Rank	hvAb	hvBb	hvAb	hvBb	hvBb	hvAb

Sample No.	266	267	268	269	270	271
As Received						
M	5.50	5.19	5.43	6.13	7.47	6.96
A	39.09	7.04	4.96	6.15	3.34	3.92
VM	25.72	36.42	36.91	41.80	40.98	42.31
FC	29.69	51.35	52.70	45.92	48.21	46.81
S	0.38	1.13	1.41	3.09	0.73	1.08
Gas Content (cm^3/gm)	3.30	0.30	0.10	0.40	0.40	0.30
As Received Btu	8,020	12,779	13,113	12,228	12,678	12,648
Moist M/m-free Btu	13,897	13,567	13,895	13,172	13,169	13,233
ASTM Rank	hvBb	hvBb	hvBb	hvBb	hvBb	hvBb

Sample No.	272	273	274	275	276	277
As Received						
M	7.85	7.13	5.73	6.87	7.50	4.98
A	5.72	3.75	7.51	8.83	3.27	13.56
VM	38.69	41.60	40.55	37.61	38.73	37.67
FC	47.74	47.52	46.21	46.69	50.50	43.79
S	0.84	0.87	4.06	1.46	0.76	0.83
Gas Content (cm^3/gm)	0.10	0.00		0.00	0.20	0.00
As Received Btu	11,981	12,451	12,081	11,755	12,396	11,495
Moist M/m-free Btu	12,788	12,996	13,248	13,029	12,866	13,491
ASTM Rank	hvCb	hvCb	hvBb	hvBb	hvCb	hvBb

Sample No.	278	279	280	281	282	283
As Received						
M	5.10	5.88	7.79	7.28	7.32	7.55
A	3.63	8.24	19.33	11.50	8.79	6.36
VM	42.45	41.32	33.49	38.27	38.98	38.52
FC	48.42	44.56	39.39	42.95	44.91	47.57
S	0.80	1.68	0.47	0.87	0.93	0.44
Gas Content (cm^3/gm)	0.60	0.10	0.00	0.00	0.00	0.00
As Received Btu	12,979	12,215	10,047	11,322	11,613	12,144
Moist M/m-free Btu	13,529	13,452	12,710	12,949	12,852	13,050
ASTM Rank	hvBb	hvBb	hvCb	hvCb	hvCb	hvBb

Sample No.	284	285	286	287	288	289
As Received						
M	9.21	8.65	6.09	6.64	6.05	2.85
A	11.39	7.65	4.67	7.77	4.88	6.46
VM	36.00	38.18	42.01	40.60	41.20	42.94
FC	43.40	45.52	47.23	44.99	47.87	47.75
S	0.42	0.50	0.54	1.05	0.56	1.24
Gas Content (cm^3/gm)	0.00	0.20	0.00	0.30	0.00	1.10
As Received Btu	11,052	11,751	12,824	12,142	12,710	13,161
Moist M/m-free Btu	12,611	12,820	13,519	13,281	13,431	14,185
ASTM Rank	hvCb	hvCb	hvBb	hvBb	hvBb	hvAb

Sample No.	290	291	292	293	294	295
As Received						
M	3.58	10.69	8.66	5.03	4.91	6.27
A	14.50	7.99	14.43	3.39	17.81	5.09
VM	39.49	38.43	33.64	48.46	35.82	41.44
FC	42.43	42.89	43.27	43.12	41.46	47.20
S	0.62	0.42	0.41	0.39	0.51	0.32
Gas Content (cm^3/gm)	0.30	0.10	0.10	0.02	0.41	0.00
As Received Btu	11,994	11,232	10,716	13,547	11,053	12,661
Moist M/m-free Btu	14,242	12,301	12,704	14,073	13,701	13,406
ASTM Rank	hvAb	hvCb	hvCb	hvAb	hvBb	hvBb

Sample No.	296	297	298	299	300	301
As Received						
M	5.34	6.16	5.06	6.23	7.03	6.52
A	9.04	5.51	4.17	8.05	4.06	3.46
VM	42.80	45.57	45.51	37.73	42.41	41.24
FC	42.82	42.76	45.26	47.99	46.50	48.78
S	0.41	0.43	0.49	0.62	0.78	0.33
Gas Content (cm^3/gm)	0.00	0.40	0.41	0.00	0.24	0.00
As Received Btu	12,337	12,795	13,213	12,158	12,651	12,916
Moist M/m-free Btu	13,683	13,616	13,850	13,332	13,250	13,426
ASTM Rank	hvBb	hvBb	hvBb	hvBb	hvBb	hvBb

Sample No.	302	303	304	305	306	307
As Received						
M	8.60	5.08	6.20	7.15	6.93	5.23
A	6.10	8.98	7.43	3.97	3.50	4.81
VM	36.79	45.35	38.92	41.78	42.73	42.66
FC	48.51	40.59	47.45	47.10	46.84	47.30
S	0.82	0.29	0.61	0.52	0.60	0.48
Gas Content (cm^3/gm)	0.00	0.48	0.30	0.10	0.10	0.00
As Received Btu	11,997	12,394	12,364	12,717	12,804	13,027
Moist M/m-free Btu	12,860	13,733	13,181	13,299	13,322	13,754
ASTM Rank	hvCb	hvBb	hvBb	hvBb	hvBb	hvBb

Sample No.	308	309	310	311	312	313
As Received						
M	10.54	7.04	8.09	3.90	3.62	3.38
A	2.79	6.02	8.92	3.96	3.18	3.30
VM	34.72	40.90	36.01	39.81	38.86	39.52
FC	51.95	46.04	46.98	52.33	54.34	53.80
S	0.39	0.28	0.35	0.48	0.42	0.88
Gas Content (cm^3/gm)	0.06	0.00	0.00	2.94	4.71	7.46
As Received Btu	12,229	12,193	11,298	13,351	13,642	13,676
Moist M/m-free Btu	12,617	13,047	12,510	13,961	14,139	14,207
ASTM Rank	hvCb	hvBb	hvCb	hvBb	hvAb	hvAb

Sample No.	314	315	316
As Received			
M	4.11	4.40	6.23
A	8.30	2.67	7.71
VM	37.75	37.48	44.20
FC	49.84	55.45	41.86
S	0.82	0.53	0.57
Gas Content (cm^3/gm)	2.83	3.50	0.21
As Received Btu	12656	13,511	12,084
Moist M/m-free Btu	13,926	13,927	13,196
ASTM Rank	hvBb	hvBb	hvBb

* Sample returned to donor.

Ultimate Analysis - This analysis includes percent moisture, carbon, hydrogen, nitrogen, chlorine, sulfur, ash, and oxygen. The analysis was accomplished on all samples except those that were required to be returned to the donor. Sixty five (65) samples from previous work are included. The values recorded in the following table are on an "As Received Basis". * Analysis not run or sample returned to donor.

ULTIMATE ANALYSIS

Sample No.	1	2	5	8	9	10	13
%Moisture	2.54	14.24	10.90	3.19	3.99	3.07	3.75
%Carbon	*	*	*	*	*	*	*
%Hydrogen	*	*	*	*	*	*	*
%Nitrogen	*	*	*	*	*	*	*
%Chlorine	*	*	*	*	*	*	*
%Sulfur	0.64	0.48	0.57	0.66	0.94	0.86	0.71
%Ash	14.97	8.20	9.47	5.80	7.71	10.94	3.21
%Oxygen	*	*	*	*	*	*	*

Sample No.	14	15	16	17	18	19	20
%Moisture	3.03	3.53	4.59	4.23	4.80	3.87	4.00
%Carbon	*	*	*	*	*	*	*
%Hydrogen	*	*	*	*	*	*	*
%Nitrogen	*	*	*	*	*	*	*
%Chlorine	*	*	*	*	*	*	*
%Sulfur	0.49	0.45	0.68	1.04	0.81	0.63	0.53
%Ash	3.50	2.58	3.92	7.12	6.11	6.01	4.12
%Oxygen	*	*	*	*	*	*	*

Sample No.	21	22	23	24	25	27	31
%Moisture	2.09	2.39	3.00	1.88	2.03	2.16	1.90
%Carbon	*	*	*	*	*	*	*
%Hydrogen	*	*	*	*	*	*	*
%Nitrogen	*	*	*	*	*	*	*
%Chlorine	*	*	*	*	*	*	*
%Sulfur	0.34	0.86	0.60	0.66	0.36	0.44	0.57
%Ash	5.55	7.72	3.96	8.26	7.41	5.56	4.10
%Oxygen	*	*	*	*	*	*	*

Sample No.	33	64	65	66	67	68	69
%Moisture	5.05	3.20	2.90	3.10	2.60	2.60	2.90
%Carbon	*	75.10	73.70	75.00	73.40	74.20	74.80
%Hydrogen	*	5.6	5.3	5.8	5.4	5.7	5.70
%Nitrogen	*	1.4	1.4	1.4	1.4	1.3	1.30
%Chlorine	*	*	*	*	*	*	*
%Sulfur	0.59	0.40	0.40	0.60	0.50	0.30	0.50
%Ash	9.77	3.50	5.20	3.00	6.50	5.90	4.50
%Oxygen	*	14.0	13.9	14.3	12.9	12.5	13.20

Sample No.	70	71	72	73	74	75	76
%Moisture	2.70	2.50	1.20	2.80	4.70	4.70	1.40
%Carbon	73.60	74.90	76.10	76.10	72.30	73.40	75.30
%Hydrogen	5.3	5.6	5.5	6.1	6.0	5.7	5.8
%Nitrogen	1.3	1.4	1.3	1.3	1.5	1.5	1.6
%Chlorine	*	*	*	*	*	*	*
%Sulfur	0.50	0.50	0.40	0.30	0.60	0.30	1.30
%Ash	6.00	4.90	5.50	5.50	6.80	4.70	6.10
%Oxygen	13.20	12.60	11.10	10.70	12.70	14.50	9.90

Sample No.	77	78	79	80	81	82	83
%Moisture	3.30	2.60	1.60	1.70	1.70	1.20	1.80
%Carbon	74.50	70.50	76.90	75.80	73.50	76.0	76.6
%Hydrogen	5.40	5.60	5.90	5.60	5.80	6.20	5.90
%Nitrogen	1.40	1.30	1.50	1.40	1.50	1.30	1.60
%Chlorine	*	*	*	*	*	*	*
%Sulfur	0.40	0.50	0.50	0.50	0.60	0.60	0.50
%Ash	4.00	8.90	4.40	6.00	7.80	5.90	5.30
%Oxygen	13.40	13.20	10.80	10.80	10.90	10.00	10.10

Sample No.	85	86	89	90	92	93	94
%Moisture	4.00	1.90	1.50	1.70	4.10	3.20	2.70
%Carbon	71.10	74.40	62.50	76.10	72.90	75.10	74.90
%Hydrogen	5.10	6.00	5.20	5.90	5.30	6.00	6.00
%Nitrogen	1.40	1.40	1.30	1.70	1.40	1.50	1.50
%Chlorine	*	*	*	*	*	*	*
%Sulfur	0.30	0.40	0.90	0.60	0.40	0.40	0.40
%Ash	6.90	6.50	20.80	5.70	6.00	3.00	4.30
%Oxygen	15.10	11.30	9.20	10.00	14.10	13.20	13.00

Sample No.	95	97	98	99	100	101	102
%Moisture	2.40	2.50	3.40	3.70	3.00	2.20	2.30
%Carbon	73.60	71.30	71.20	72.90	73.90	72.60	75.90
%Hydrogen	6.00	5.60	5.60	5.60	5.50	5.90	5.80
%Nitrogen	1.40	1.40	1.40	1.50	1.40	1.30	1.50
%Chlorine	*	*	*	*	*	*	*
%Sulfur	0.31	0.40	0.70	0.40	0.30	0.40	0.60
%Ash	5.80	7.70	7.10	4.90	5.10	8.40	5.20
%Oxygen	12.80	13.70	14.20	14.70	13.80	11.40	11.00

Sample No.	103	108	109	113	114	162	165
%Moisture	2.20	2.10	2.40	2.00	1.70	1.80	4.09
%Carbon	74.00	71.80	73.90	73.60	75.60	71.40	62.26
%Hydrogen	5.80	6.00	5.60	5.70	5.80	5.40	4.57
%Nitrogen	1.40	1.40	1.50	1.50	1.50	1.40	0.96
%Chlorine	*	*	*	*	*	*	0.02S
Sulfur	0.40	0.70	0.70	0.70	0.50	0.40	2.87
%Ash	6.80	8.80	6.00	7.20	5.90	10.90	16.95
%Oxygen	11.60	11.10	12.30	11.30	10.80	10.60	8.28

Sample No.	168	170	172	178	179	180	181
%Moisture	5.40	2.54	3.37	3.14	3.51	3.38	3.25
%Carbon	73.10	72.75	72.11	64.93	67.02	71.42	62.59
%Hydrogen	5.11	5.19	5.11	4.84	4.83	5.24	4.39
%Nitrogen	1.44	1.19	1.28	1.19	1.22	1.38	1.31
%Chlorine	0.01	0.04	0.03	0.01	0.02	0.02	0.05
%Sulfur	1.21	0.56	1.65	2.75	0.79	2.40	0.83
%Ash	4.02	8.91	7.61	14.37	13.81	7.22	19.50
%Oxygen	9.71	8.82	8.84	8.77	8.80	9.05	8.08

Sample No.	183	184	185	187	190	191	192
%Moisture	3.32	3.00	4.78	3.58	5.57	6.76	5.63
%Carbon	69.01	64.96	73.56	61.12	69.93	64.61	65.42
%Hydrogen	5.32	4.60	5.26	4.44	5.17	4.68	4.80
%Nitrogen	1.16	1.17	1.42	1.02	1.57	1.12	1.37
%Chlorine	0.00	0.02	0.00	0.01	0.01	0.00	0.00
%Sulfur	0.90	1.92	1.31	1.69	0.72	0.28	0.70
%Ash	10.55	15.30	3.74	18.61	7.79	12.62	12.13
%Oxygen	9.74	9.03	9.93	9.53	9.24	9.93	9.95

Sample No.	193	194	197	198	200	201	202
%Moisture	2.65	3.17	2.87	3.53	8.27	2.99	7.35
%Carbon	74.84	71.98	43.40	65.45	68.63	71.64	53.09
%Hydrogen	5.50	4.79	3.71	4.75	4.65	5.32	4.09
%Nitrogen	1.47	1.21	0.83	0.03	1.09	1.25	1.00
%Chlorine	0.03	0.05	0.01	0.03	0.02	0.06	0.00
%Sulfur	1.15	0.76	0.78	3.15	0.29	1.46	0.72
%Ash	5.13	9.13	39.90	13.40	5.69	8.74	23.50
%Oxygen	9.23	8.91	8.50	8.55	11.36	8.54	10.25

Sample No.	203	204	205	206	207	208	209
%Moisture	11.28	4.32	5.63	4.43	2.84	4.30	3.16
%Carbon	64.18	69.55	65.74	70.99	61.25	73.18	71.28
%Hydrogen	4.31	4.56	4.62	4.91	4.83	5.06	4.89
%Nitrogen	1.16	1.18	1.14	1.40	1.35	1.39	1.23
%Chlorine	0.01	0.02	0.00	0.11	0.07	0.05	0.04
%Sulfur	0.67	0.67	1.33	2.14	6.58	0.81	1.02
%Ash	7.32	9.88	12.98	7.23	17.26	4.70	9.24
%Oxygen	11.07	9.82	8.56	8.79	5.82	10.51	9.14

Sample No.	210	211	212	213	214	215	216
%Moisture	3.76	6.32	7.42	5.02	1.93	7.66	8.07
%Carbon	72.81	53.85	67.30	67.64	74.45	68.36	61.93
%Hydrogen	5.03	3.99	4.59	4.52	5.39	4.74	4.37
%Nitrogen	1.06	1.01	1.15	1.29	1.50	1.15	0.96
%Chlorine	0.05	0.00	0.00	0.02	0.08	0.02	0.00
%Sulfur	0.90	0.52	0.63	0.66	0.74	0.31	0.65
%Ash	6.35	25.09	8.26	10.20	6.27	6.89	13.91
%Oxygen	10.04	9.22	10.65	10.65	9.64	10.87	10.11

Sample No.	217	218	219	220	221	222	223
%Moisture	2.80	10.78	8.52	4.50	3.19	10.18	3.26
%Carbon	53.44	66.38	69.05	70.71	60.19	65.52	62.22
%Hydrogen	3.89	4.53	4.68	4.87	4.34	4.54	4.67
%Nitrogen	1.16	1.09	1.17	1.30	1.19	1.01	1.31
%Chlorine	0.05	0.00	0.01	0.03	0.01	0.00	0.01
%Sulfur	0.65	0.46	0.35	0.53	3.36	1.04	7.33
%Ash	29.33	6.13	5.07	8.12	19.93	7.06	15.11
%Oxygen	8.68	10.63	11.15	10.42	7.79	10.65	6.09

Sample No.	224	225	226	227	228	229	230
%Moisture	6.77	8.49	5.66	5.83	8.46	2.20	3.44
%Carbon	67.99	69.55	71.01	68.64	65.87	65.81	55.67
%Hydrogen	5.25	5.24	5.46	5.08	4.82	4.56	3.88
%Nitrogen	1.37	1.23	1.29	1.08	1.23	1.30	0.88
%Chlorine	0.07	0.02	0.08	0.00	0.01	0.08	0.01
%Sulfur	0.65	0.50	0.93	0.81	1.06	0.54	0.37
%Ash	7.08	3.51	5.05	7.83	6.91	16.26	27.23
%Oxygen	10.82	11.46	10.52	10.73	11.64	9.25	8.52

Sample No.	231	232	233	234	235	236	237
%Moisture	8.37	7.72	6.97	8.14	4.84	5.89	2.90
%Carbon	71.45	65.40	67.37	66.85	73.42	68.32	76.28
%Hydrogen	5.04	4.77	4.61	5.01	5.36	5.17	5.37
%Nitrogen	1.18	0.96	1.16	1.27	1.28	1.22	1.52
%Chlorine	0.02	0.02	0.01	0.03	0.03	0.02	0.08
%Sulfur	0.47	0.55	0.62	0.76	0.63	0.57	0.54
%Ash	2.30	9.40	8.15	6.71	4.07	9.14	3.61
%Oxygen	11.17	11.18	11.11	11.23	10.37	9.67	9.70

Sample No.	238	239	240	241	242	243	244
%Moisture	8.05	5.18	7.01	9.32	7.37	6.46	6.83
%Carbon	47.15	62.94	71.65	70.47	72.27	72.85	70.40
%Hydrogen	3.78	5.12	5.26	4.98	5.09	5.21	5.18
%Nitrogen	0.92	1.19	1.39	1.59	1.32	1.50	1.52
%Chlorine	0.00	0.00	0.02	0.02	0.02	0.01	0.01
%Sulfur	0.63	1.52	0.39	0.56	0.47	0.41	0.53
%Ash	30.03	14.13	3.64	2.13	3.00	2.70	4.84
Oxygen	9.44	9.92	10.64	10.93	10.46	10.86	10.69

Sample No.	245	246	247	248	249	250	251
%Moisture	7.61	2.82	6.00	4.68	4.15	5.69	4.99
%Carbon	72.62	76.25	71.77	70.51	71.54	74.48	71.16
%Hydrogen	5.06	5.08	5.31	5.00	4.54	4.88	5.42
%Nitrogen	1.55	1.67	1.35	1.33	1.28	1.37	1.45
%Chlorine	0.03	0.01	0.02	0.02	0.02	0.02	0.02
%Sulfur	0.68	0.79	0.35	0.87	0.48	0.60	0.48
%Ash	3.10	4.24	4.79	8.17	9.29	2.45	5.27
%Oxygen	9.35	9.14	10.41	9.42	8.70	10.51	11.21

Sample No.	252	253	254	255	256	257	258
%Moisture	4.91	7.13	2.62	3.27	6.77	3.84	1.95
%Carbon	69.68	68.96	71.94	66.87	66.30	61.79	72.71
%Hydrogen	5.13	4.69	4.98	4.76	4.64	4.48	5.37
%Nitrogen	1.34	1.22	1.28	1.39	1.64	1.32	1.66
%Chlorine	0.03	0.01	0.03	0.11	0.02	0.00	0.08
%Sulfur	0.47	0.46	0.53	0.62	0.58	0.75	0.83
%Ash	7.38	8.71	9.82	13.19	11.96	17.97	9.64
%Oxygen	11.06	8.82	8.80	9.79	8.13	9.85	7.76

Sample No.	259	260	261	262	263	264	265
%Moisture	5.91	2.07	2.59	2.50	8.17	3.71	3.21
%Carbon	70.06	74.02	73.73	78.48	70.27	64.91	74.40
%Hydrogen	5.28	4.92	5.33	4.32	5.25	4.91	5.28
%Nitrogen	1.38	1.30	1.55	1.58	1.51	1.52	1.54
%Chlorine	0.05	0.02	0.07	0.06	0.06	0.06	0.07
%Sulfur	0.54	0.42	0.91	0.48	0.52	2.46	1.10
%Ash	6.48	11.69	4.46	5.01	3.19	14.06	5.71
%Oxygen	10.30	5.56	11.36	7.57	11.03	8.37	8.69

Sample No.	266	267	268	269	270	271	272
%Moisture	5.50	5.19	5.43	6.13	7.47	6.96	5.72
%Carbon	44.81	71.44	73.86	68.54	70.88	70.36	68.10
%Hydrogen	3.35	5.08	5.17	4.69	5.23	5.36	4.78
%Nitrogen	1.46	1.37	1.30	1.19	1.33	1.42	1.23
%Chlorine	0.06	0.05	0.05	0.13	0.11	0.10	0.03
%Sulfur	0.38	1.13	1.41	3.09	0.73	1.08	0.84
%Ash	39.09	7.04	4.96	6.15	3.34	3.92	5.72
%Oxygen	5.35	8.70	7.82	10.08	10.91	10.80	11.45

Sample No.	273	274	275	276	277	278	279
%Moisture	7.13	5.73	6.87	7.50	4.98	5.10	5.88
%Carbon	69.71	66.74	66.44	68.93	64.73	71.61	67.79
%Hydrogen	5.03	4.84	4.59	5.07	4.57	5.27	4.96
%Nitrogen	1.46	0.79	1.21	1.49	1.29	1.40	1.38
%Chlorine	0.13	0.11	0.02	0.11	0.11	0.12	0.11
%Sulfur	0.87	4.06	1.46	0.76	0.83	0.80	1.68
%Ash	3.75	7.51	8.83	3.27	13.56	3.63	8.24
%Oxygen	11.92	10.22	10.58	12.87	9.93	12.07	9.96

Sample No.	280	281	282	283	284	285	286
%Moisture	7.79	7.28	7.32	7.55	9.21	8.65	6.09
%Carbon	57.24	64.64	65.53	68.62	63.14	66.71	71.32
%Hydrogen	4.07	4.49	4.75	4.93	4.39	4.85	5.31
%Nitrogen	1.00	1.03	1.18	1.23	1.04	1.19	1.31
%Chlorine	0.01	0.01	0.06	0.04	0.02	0.01	0.01
%Sulfur	0.47	0.87	0.93	0.44	0.42	0.50	0.54
%Ash	19.33	11.50	8.79	6.36	11.39	7.65	4.67
%Oxygen	10.09	10.18	11.44	10.83	10.39	10.44	10.75

Sample No.	287	288	289	290	291	292	293
%Moisture	6.64	6.05	2.85	3.58	10.69	8.66	5.03
%Carbon	67.96	71.67	72.67	65.67	63.68	58.47	74.02
%Hydrogen	5.06	5.26	5.44	5.03	4.64	4.38	5.82
%Nitrogen	1.18	1.32	1.47	1.35	1.12	1.00	1.24
%Chlorine	0.01	0.01	0.03	0.00	0.01	0.01	0.02
%Sulfur	1.05	0.56	1.24	0.62	0.42	0.41	0.39
%Ash	7.77	4.88	6.46	14.50	7.99	14.43	3.39
%Oxygen	10.33	10.25	9.84	9.25	11.45	12.64	10.09

Sample No.	294	295	296	297	298	299	300
%Moisture	4.91	6.27	5.34	6.16	5.06	6.23	7.03
%Carbon	62.42	71.42	68.49	71.05	73.14	68.47	70.33
%Hydrogen	4.48	5.17	5.26	5.43	5.67	4.80	5.19
%Nitrogen	0.88	1.39	1.38	1.15	1.33	0.71	1.61
%Chlorine	0.03	0.01	0.00	0.01	0.03	0.01	0.03
%Sulfur	0.51	0.32	0.41	0.43	0.49	0.62	0.78
%Ash	17.81	5.09	9.04	5.51	4.17	8.05	4.06
%Oxygen	8.96	10.33	10.08	10.26	10.11	11.11	10.97

Sample No.	301	302	303	304	305	306	307
%Moisture	6.52	8.60	5.08	6.20	7.15	6.93	5.23
%Carbon	72.24	67.96	68.58	69.75	70.88	71.19	72.03
%Hydrogen	5.07	4.85	5.38	4.80	5.07	5.41	5.30
%Nitrogen	1.38	1.29	1.10	1.38	1.51	1.59	1.49
%Chlorine	0.00	0.00	0.01	0.01	0.00	0.00	0.00
%Sulfur	0.33	0.75	0.29	0.61	0.52	0.60	0.48
%Ash	3.46	6.10	8.98	7.43	3.97	3.50	4.81
%Oxygen	11.00	10.45	10.58	9.82	10.90	10.78	10.66

Sample No.	308	309	310	311	312	313	314
%Moisture	10.54	7.04	8.09	3.90	3.62	3.38	4.11
%Carbon	69.74	69.67	65.36	75.26	76.63	76.70	71.08
%Hydrogen	4.56	4.90	4.38	5.28	5.18	5.34	5.02
%Nitrogen	1.15	1.07	1.08	1.56	1.61	1.66	1.55
%Chlorine	0.00	0.00	0.00	0.07	0.07	0.06	0.07
%Sulfur	0.39	0.28	0.35	0.48	0.42	0.88	0.82
%Ash	2.79	6.02	8.92	3.96	3.18	3.30	8.30
%Oxygen	10.83	11.02	11.82	9.49	9.29	8.68	9.05

Sample No.	315	316
%Moisture	4.11	4.40
%Carbon	71.08	75.89
%Hydrogen	5.02	5.11
%Nitrogen	1.55	1.52
%Chlorine	0.07	0.08
%Sulfur	0.82	0.53
%Ash	8.30	2.67
%Oxygen	9.05	9.80

FAVORABLE AREAS FOR PROSPECT EVALUATION

For our purposes, coal containing one (1) to five (5) cubic centimeters of gas has been considered as moderately gassy coal, while coal with greater than five (5) cubic centimeters has been considered as gassy coal. Although this working classification is admittedly somewhat arbitrary, the upper range of moderately gassy (3 - 5 cm^3) coal and gassy coal (greater than 5 cm^3) sample locations are considered as favorable areas for prospect evaluation. The following table delineates these areas

Sample No.	Geo-coordinates	Coal Field	Coal Zone/Bed	Gas Content cm^3/gram
264	31-22S-06E	Emery	G	4.70
266	06-23S-06E	Emery	G	3.30
80	28-12S-09E	Book Cliffs	Castlegate A	3.90
237	28-12S-09E	Book Cliffs	Castlegate D	4.80
79	28-12S-09E	Book Cliffs	Castlegate D	5.57
88	28-12S-09E	Book Cliffs	Castlegate A	7.08
81	28-12S-09E	Book Cliffs	Castlegate A	7.15
89	28-12S-09E	Book Cliffs	Subseam 1	7.40
82	28-12S-09E	Book Cliffs	Subseam 1	8.25
83	28-12S-09E	Book Cliffs	Subseam 2	8.43
72	28-12S-09E	Book Cliffs	Castlegate A	8.93
73	28-12S-09E	Book Cliffs	Castlegate A	9.40
255	33-12S-09E	Book Cliffs	Kennilworth	6.60
94	05-13S-09E	Book Cliffs	Castlegate B	3.00
31	26-12S-10E	Book Cliffs	Kenilworth	10.94
114	27-12S-10E	Book Cliffs	Castlegate C	10.63
113	27-12S-10E	Book Cliffs	Kenilworth	11.02
261	34-12S-12E	Book Cliffs	Sunnyside(1)	5.30
262	34-12S-12E	Book Cliffs	Gilson	6.60
260	34-12S-12E	Book Cliffs	Gilson	9.40
8	04-13S-12E	Book Cliffs	Sunnyside	4.76
9	04-13S-12E	Book Cliffs	Rock Canyon(1)	5.39
313	13-13S-12E	Book Cliffs	Rock Canyon	7.46
312	15-13S-12E	Book Cliffs	Gilson	4.71
315	16-13S-12E	Book Cliffs	Gilson	3.50
16	17-14S-14E	Book Cliffs	Sunnyside	3.36
14	17-14S-14E	Book Cliffs	Sunnyside	3.69
15	17-14S-14E	Book Cliffs	Sunnyside	4.04

IN-MINE COAL CHIP SAMPLING

The Utah Geological and Mineral Survey sampled coal-chips from underground horizontal drilling in the Rock Canyon coal bed at the Soldier Canyon Mine, section 18, T13S, R12E. Collections were made from a "T" fitting located in the return line on a Fletcher Long Hole Drill being used by Resource Enterprise Incorporated to drill a test hole, designated REI-GH-1. This drilling occurred during the period 9 November 1982 through 15 November 1982.

The second drill hole sampled from underground horizontal drilling in the Rock Canyon coal bed at the same mine has been designated REI-GH-3. The hole was drilled during the period 16 February 1983 through 29 March 1983.

The objectives of sampling were:

a. To obtain a methane profile of the coal bed from rib to drill hole terminus.

b. To accumulate data for possible correlative elements.

c. To investigate the physical characteristics of the coal bed reservoir.

d. To develop possible methane content predictive techniques.

The following procedures were used for sample collection:

a. A full cannister of cuttings was collected, where possible, at 20 ft. increments until 100 feet was reached. Thereafter, cuttings were collected every 50 feet.

b. Chips were not washed prior to sealing in the cannister since water only was used as a drilling fluid.

c. Prior to sealing, samples were placed in a relatively pourous cloth bag, hand-centrifuged, then emptied into the cannister. Each cannister was filled with chips to within one inch of the top and immediately sealed.

d. Time was recorded as the particular increment being collected was cut. "Direct Method" procedures for determining lost gas were followed even though, possibly, a larger than normal portion of gas was lost because of drilling method. The initial volume of gas desorbed was plotted as a function of time until the rate of desorption slowed, or for approximately two hours. The values were graphed and lost gas determined.

e. When the desorption rate dropped to less than 10 cm^3 per day for five successive days, desorption monitoring was discontinued. The sample was then dried, weighed and the percent water calculated.

f. After air drying, the samples were individually screen-sized and weighed. A density separation was made of each increment to separate coal from rock.

g. Residual gas was determined from the larger screen sizes by grinding the chips to 200 mesh or smaller and measuring the residual gas.

h. An average gas content (0.12 cm^3/gm) from seven siltstone, sandstone, and shale roof and floor core samples, previously collected, was used to obtain an average value for the rock chip component of the sample. The weight of the rock contained in the overall sample was multiplied by this factor and the product subtracted from the lost and desorbed gas content.

i. Total gas content was determined by dividing the two gas components, lost and desorbed, minus the gas assigned to the rock component by the sample weight and adding the results to the residual gas component.

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DATA PRESENTATION:

Sample Identification: REI-GH-1, 20 ft. increment-horizontal

Sample Weight: 2,290 grams

Sample Weight Dry: 1,533 grams*

Screen Size	Rock(gm)	Coal(gm)	Total Weight	Percent
10	32.5	339.5	415.5	27.1
20	43.5	793.5	895.5	58.4
40	11.5	184.0	211.5	13.8
60	-0-	5.5	6.0	0.4
100	-0-	-0-	1.0	0.08
200	-0-	-0-	1.0	0.06
-200	-0-	-0-	2.5	0.16

*Includes 118.0 grams of grout.

LOST GAS: 185 cm^3

DESORBED GAS: 2054 cm^3

RESIDUAL GAS: 0.1 cm^3/gm

TOTAL GAS CONTENT: 1.8 cm^3/gm or 57.6 ft^3/ton in place

Sample Identification: REI-GH-1, 40 ft. increment-horizontal

Sample Weight: 2,962 grams

Sample Weight Dry: 2,381 grams

Screen Size	Rock(gm)	Coal(gm)	Total Weight	Percent
4	56.5	1.5	58.0	2.4
10	644.5	49.0	693.5	29.1
20	1,118.0	96.0	1,214.0	51.1
60	60.5	16.5	77.0	3.2
100	19.5	8.0	27.5	1.2
200	13.0	5.5	18.5	0.8
-200	19.8	2.2	22.0	0.8

LOST GAS: 185 cm^3

DESORBED GAS: 2044 cm^3

RESIDUAL GAS: 0.1 cm^3/gm

TOTAL GAS CONTENT: 3.65 cm^3/gm or 116.8 ft^3/ton in place

Sample Identification: REI-GH-1, 60 ft. increment-horizontal

Sample Weight: 2,530 grams

Sample Weight Dry: 2,148 grams

Screen Size	Rock(gm)	Coal(gm)	Total Weight	Percent
4	44.5	5.0	49.5	2.3
10	752.0	83.5	835.5	38.9
20	883.5	98.0	981.5	45.7
40	185.5	20.5	206.0	9.6
60	44.5	5.0	49.5	2.3
100	13.5	1.5	15.0	0.7
200	7.5	1.0	8.5	0.4
-200	0.1	0.1	2.5	0.1

LOST GAS: 75 cm^3

DESORBED GAS: 258 cm^3

RESIDUAL GAS: 0.0 cm^3/gm

TOTAL GAS CONTENT: 0.47 cm^3/gm or 15.1 ft^3/ton in place

Sample Identification: REI-GH-1, 100 ft. increment-horizontal

Sample Weight: 2,667 grams

Sample Weight Dry: 1902 grams

Screen Size	Rock(gm)	Coal(gm)	Total Weight	Percent
4	3.5	0.0	3.5	0.2
10	94.5	3.5	98.0	5.6
20	1,061.5	109.5	1171.0	66.8
40	291.0	53.0	344.0	20.0
60	52.5	17.0	69.5	4.0
100	15.5	7.5	23.0	1.3
200	7.1	6.9	14.0	0.8
-200	27.5	3.5	31.0	1.3

LOST GAS: 47 cm^3

DESORBED GAS: 781 cm^3

RESIDUAL GAS: 0.32 cm^3/gm

TOTAL GAS CONTENT: 3.50 cm^3/gm or 112.6 ft^3/ton in place

Sample Identification: REI-GH-1, 120 ft. increment-horizontal

Sample Weight: 2,261.5 grams

Sample Weight Dry: 1,591.0 grams

Screen Size	Rock(gm)	Coal(gm)	Total Weight	Percent
4	2.0	0.0	2.0	0.1
10	9.5	40.0	49.5	3.1
20	123.3	904.2	1,027.5	64.6
40	66.5	297.5	364.5	22.9
60	13.5	62.5	76.0	4.8
100	5.5	24.5	30.0	1.9
200	3.5	14.5	18.0	1.1
-200	3.8	20.7	24.5	1.5

LOST GAS: 254.0 cm^3

DESORBED GAS: 2,387.0 cm^3

RESIDUAL GAS: 0.07 cm^3/gm

TOTAL GAS CONTENT: 1.99 cm^3/gm or 63.7 ft^3/ton in place

Sample Identification: REI-GH-1, 150 ft. increment-horizontal

Sample Weight: 3,379.5 grams

Sample Weight Dry: 2,590.0 grams

Screen Size	Rock(gm)	Coal(gm)	Total Weight	Percent
10	25.3	1.2	26.5	1.0
20	1163.8	50.7	1214.5	46.9
40	971.5	61.5	1033.0	61.5
60	151.0	31.0	182.0	7.0
100	45.0	21.5	66.5	2.6
200	20.5	19.0	39.5	1.5
-200	26.0	2.0	28.0	1.1

LOST GAS: 322.0 cm^3

DESORBED GAS: 1,503.0 cm^3

RESIDUAL GAS: 0.0 cm^3/gm

TOTAL GAS CONTENT: 8.10 cm^3/gm or 259.3 ft^3/ton in place

Sample Identification: REI-GH-1, 200 ft. increment-horizontal

Sample Weight: 2,160.0 grams

Sample Weight Dry: 1,479.5 grams

Screen Size	Rock(gm)	Coal(gm)	Total Weight	Percent
4	6.5	0.0	6.5	0.4
10	0.5	3.5	4.0	0.3
20	46.5	729.5	776.0	52.5
40	24.0	480.5	504.5	34.1
60	8.5	107.0	115.5	7.8
100	3.0	40.0	43.0	2.9
200	2.0	18.0	20.0	1.4
-200	0.7	9.3	10.0	0.6

LOST GAS: 324.0 cm^3

DESORBED GAS: 2,337.0 cm^3

RESIDUAL GAS: 0.02 cm^3/gm

TOTAL GAS CONTENT: 1.93 cm^3/gm or 61.7 ft^3/ton in place

Sample Identification: REI-GH-1, 300 ft. increment-horizontal

Sample Weight: 2,267.5 grams

Sample Weight Dry: 1,648.5 grams

Screen Size	Rock(gm)	Coal(gm)	Total Weight	Percent
20	5.0	49.5	54.5	3.3
40	33.0	334.5	367.5	22.3
60	40.1	601.5	661.0	40.1
100	32.5	330.0	362.5	22.0
200	18.0	181.5	199.5	12.1
-200	0.0	3.5	3.5	0.2

LOST GAS: 288.0 cm^3

DESORBED GAS: 703.0 cm^3

RESIDUAL GAS: 0.05 cm^3/gm

TOTAL GAS CONTENT: 0.70 cm^3/gm or 22.4 ft^3/ton in place

GAS ANALYSIS

SAMPLE #	O_2	N_2	Ar	CO_2	CH_4	CO	C_2H_6
20 ft.	2.42	11.36	0.13	1.50	83.25	0.0022	1.32
40 ft.	2.28	30.97	0.37	2.95	61.85	0.0048	1.57
100 ft.	5.30	28.60	0.34	2.48	61.15	0.0044	1.86
120 ft	2.27	10.06	0.12	4.44	80.60	0.0022	2.36
150 ft.	2.44	16.48	0.20	0.17	78.30	0.0034	2.17
200 ft.	2.44	10.53	0.13	3.16	82.95	0.0019	0.58

SAMPLE #	H_2	C_3H_8	C_4H_{10}	C_5H_{12}
20 ft.	N.D.	-------	0.0039	0.0005
40 ft.	N.D.	0.0102	0.0056	0.0007
100 ft.	0.25	0.0049	0.0054	0.0007
120 ft.	0.15	N.D.	0.0008	0.0002
150 ft.	0.20	0.0327	0.0106	0.0008
200 ft.	0.20	0.0004	0.0013	0.0003

Gas was collected from the cannisters underwater to avoid atmospheric contamination of the sample. However, the cannisters had not desorbed over sufficient time to purge the inner space. Some of the O_2, N_2 values may reflect atmoshperic contamination.

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Sample Identification: REI-GH-3, 80 ft. increment-horizontal.

Sample Weight: 726.5 gms.

Sample Weight Dry: 525.0 gms.

LOST GAS: 174 cm^3

DESORBED GAS: 4,765 cm^3

RESIDUAL GAS: 9 cm^3

TOTAL GAS CONTENT: 9.43 cm^3/gram or 301.76 ft^3/ton in place.

Size and Weight Analysis

Screen Size	Rock(gm)	Coal(gm)	Total Weight(gm)	Percent
4	10.2	29.3	39.5	7.5
10	35.1	134.8	169.9	32.4
20	29.5	125.7	155.2	29.6
40	10.5	64.5	75.0	14.3
60	3.7	33.3	37.0	7.0
80	1.3	15.4	16.7	3.2
100	0.2	6.2	6.4	1.2
200	0.6	14.8	15.4	3.0
-200	0.7	9.2	9.9	1.9
Totals	91.8	433.2	525.0	100.0

Sample Identification: REI-GH-3, 100 ft. increment-horizontal.

Sample Weight: 1,824.5 gms.

Sample Weight Dry: 1,466.5 gms

LOST GAS: 164 cm^3

DESORBED GAS: 1,938 cm^3

RESIDUAL GAS: 0.0 cm^3

TOTAL GAS CONTENT: 11.01 cm^3/gram or 352 ft^3/ton in place

Size and Weight Analysis

Screen Size	Rock(gm)	Coal(gm)	Total Weight(gm)	Percent
4	88.0	5.0	93.0	6.4
10	494.8	39.2	534.0	36.4
20	433.0	62.0	495.0	33.8
40	171.6	35.4	207.0	14.1
60	50.1	16.4	66.5	4.5
100	22.6	9.4	32.0	2.2
200	15.6	6.4	22.0	1.5
-200	14.0	3.0	17.0	1.1
Total	1,289.7	176.8	1,466.5	100.0

Sample Identification: REI-GH-3, 150 ft. increment-horizontal.

Sample Weight: 2,768.5 gms

Sample Weight Dry: 2,288.0 gms

LOST GAS: 169.0 cm^3

DESORBED GAS: 952 cm^3

RESIDUAL GAS: 0.0 cm^3

TOTAL GAS CONTENT: The total gas content computes to be 61.5 cm^3/gram. However, note the coal weight to rock weight. If the coal contained 11.0 cm^3/gram as in the previous samples the rock would have to carr, 0.43 cm^3/gram which is possible, but not consistent with the rest of the data or previous experience. Therefore, this sample will be noted, but excluded in analysis.

Size and Weight Analysis

Screen Size	Rock(gm)	Coal(gm)	Total Weight(gm)	Percent
4	236.2	0.8	237.0	10.4
10	919.8	1.2	921.0	40.3
20	719.5	3.5	723.0	31.6
40	252.9	3.1	256.0	11.2
60	72.3	2.7	75.0	3.3
100	28.6	0.4	29.0	1.3
200	21.9	1.1	23.0	1.0
-200	23.0	1.0	24.0	1.0

Sample Identification: REI-GH-3, 335 ft. increment-horizontal

Sample Weight: 717 grams

Sample Weight Dry: 460 grams

LOST GAS: 490 cm^3

DESORBED GAS: 1,297 cm^3

RESIDUAL GAS: 0.0 cm^3

TOTAL GAS CONTENT: 6.4 cm^3/gram or 204.4 ft^3/ton in place.

Size and Weight Analysis

Screen Size	Rock(gm)	Coal(gm)	Total Weight(gm)	Percent
4	4.0	1.0	5.0	1.1
10	7.7	4.3	12.0	2.6
20	17.0	38.0	55.0	12.0
40	89.5	86.5	176.0	38.3
60	39.0	72.0	111.0	24.1
100	8.5	45.5	54.0	11.7
200	8.0	6.5	30.0	6.5
-200	10.0	7.0	17.0	3.7

Sample Identification: REI-GH-3, 375.5 ft. increment-horizontal

Sample Weight: 669.5 grams

Sample Weight Dry: 451.5 grams

LOST GAS: 500 cm^3

DESORBED GAS: 1,345 cm^3

RESIDUAL GAS: 0.0 cm^3

TOTAL GAS CONTENT: 5.98 cm^3/gram or 191.4 ft^3/ton in place

Size and Weight Analysis

Screen Size	Rock(gm)	Coal(gm)	Total Weight(gm)	Percent
4	80.0	0.0	80.0	17.7
10	29.2	0.8	30.0	6.6
20	9.7	41.3	51.0	11.3
40	11.4	97.1	108.5	24.0
60	6.2	76.8	83.0	18.4
100	2.8	46.7	49.5	11.0
200	1.5	31.0	32.5	7.2
-200	4.9	12.1	17.0	3.8

Sample Identification: REI-GH-3, 416 ft. increment-horizontal

Sample Weight: 1,044 grams

Sample Weight Dry: 749 grams

LOST GAS: 826 cm^3

DESORBED GAS: 1,758 cm^3

RESIDUAL GAS: 0.0 cm^3

TOTAL GAS CONTENT: 5.74 cm^3/gram or 183.6 ft^3/ton in place

Size and Weight Analysis

Screen Size	Rock(gm)	Coal(gm)	Total Weight(gm)	Percent
4	169.4	0.1	169.5	22.6
10	48.2	0.8	49.0	6.5
20	15.7	35.8	51.5	7.0
40	21.7	131.3	153.0	20.4
60	21.0	112.5	133.5	17.8
100	3.8	88.2	92.0	11.3
200	7.4	52.6	60.0	8.0
-200	17.7	22.8	40.5	5.4
Total	304.9	444.1	749.0	100.0

Sample Identification: REI-GH-3, 478.5 ft. increment-horizontal

Sample Weight: 466.5 grams

Sample Weight Dry: 393.5 grams

LOST GAS: 581 cm^3

DESORBED GAS: 745 cm^3

RESIDUAL GAS: 0.0 cm^3

TOTAL GAS CONTENT: 6.46 cm^3/gram or 206.7 ft^3/ton in place

Size and Weight Analysis

Screen Size	Rock(gm)	Coal(gm)	Total Weight(gm)	Percent
4	74.5	0.0	74.5	19.0
10	20.4	0.1	20.5	5.2
20	22.5	2.0	24.5	6.2
40	31.6	22.4	54.0	13.7
60	22.0	42.5	64.5	16.4
100	11.7	52.8	64.5	16.4
200	6.7	48.8	55.5	14.1
-200	2.4	33.1	35.5	9.0

Sample Identification: REI-GH-3, 518.5 ft. increment-horizontal

Sample Weight: 772.0 grams

Sample Weight Dry: 511.0 grams

LOST GAS: 643 cm^3

DESORBED GAS: 1,937 cm^3

RESIDUAL GAS: 30 cm^3

TOTAL GAS CONTENT: 6.12 cm^3/gram or 195.8 ft^3/ton in place

Size and Weight Analysis

Screen Size	Rock(gm)	Coal(gm)	Total Weight(gm)	Percent
4	5.0	0.0	5.0	1.0
10	2.0	0.5	2.5	0.5
20	1.3	15.2	16.5	3.2
40	9.0	72.5	81.5	16.0
60	25.2	110.3	135.5	26.5
80	12.4	70.1	82.5	16.1
100	14.6	39.9	54.5	10.7
200	15.5	77.0	92.5	18.1
-200	1.1	39.4	40.5	7.9

Sample Identification: REI-GH-3, 586 ft. increment-horizontal

Sample Weight: 1,624.5 grams

Sample Weight Dry: 1,083.5 grams

LOST GAS: 1,050 cm^3

DESORBED GAS: 4,833 cm^3

RESIDUAL GAS: 8 cm^3

TOTAL GAS CONTENT: 6.17 cm^3/gram or 197.4 ft^3/ton in place

Size and Weight Analysis

Screen Size	Rock(gm)	Coal(gm)	Total Weight(gm)	Percent
4	40.0	0.0	40.0	3.7
10	35.3	2.7	38.0	3.5
20	13.9	141.4	155.3	14.3
40	2.2	332.5	334.7	30.0
60	11.5	215.2	226.7	21.9
80	27.0	92.4	95.1	8.8
100	15.1	47.5	62.6	5.8
200	4.8	87.5	92.3	8.5
-200	6.2	32.6	38.8	3.5

Sample Identification: REI-GH-3, 656 ft. increment-horizontal

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Sample Weight: 1,606.0 grams

Sample Weight Dry: 1,175.5 grams

LOST GAS: 910 cm^3

DESORBED GAS: 4,100 cm^3

RESIDUAL GAS: 0.0 cm^3

TOTAL GAS CONTENT: 4.72 cm^3/gram or 151.0 ft^3/ton in place

Size and Weight Analysis

Screen Size	Rock(gm)	Coal(gm)	Total Weight(gm)	Percent
4	1.6	8.2	9.8	0.8
10	7.2	98.4	105.6	9.0
20	28.1	479.4	507.5	43.2
40	56.8	291.2	348.0	29.6
60	14.3	99.2	113.5	9.7
80	2.8	33.5	36.3	3.1
100	3.1	13.7	16.9	1.4
200	0.9	24.9	25.8	2.2
-200	1.7	10.4	12.1	1.0

Sample Identification: REI-GH-3, 726 ft. increment-horizontal

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Sample Weight: 1,623.0 grams

Sample Weight Dry: 1,079.0 grams

LOST GAS: 1,360 cm^3

DESORBED GAS: 4,905 cm^3

RESIDUAL GAS: 23 cm^3

TOTAL GAS CONTENT: 6.53 cm^3/gram or 209.0 ft^3 in place

Size and Weight Analysis

Screen Size	Rock(gm)	Coal(gm)	Total Weight(gm)	Percent
4	55.2	0.3	55.5	5.1
10	13.1	6.4	19.5	1.8
20	3.2	145.0	148.2	13.8
40	2.4	355.0	357.4	33.1
60	2.3	208.0	210.3	19.5
80	0.5	89.5	90.0	8.4
100	17.7	31.3	49.0	4.5
200	3.2	98.5	101.7	9.4
-200	20.6	26.8	47.4	4.4

Sample Identification: REI-GH-3, 808 ft. increment-horizontal

Sample Weight: 1,836.0 grams

Sample Weight Dry: 1,198 grams

LOST GAS: 1,575 cm^3

DESORBED GAS: 5,615 cm^3

RESIDUAL GAS: 57 cm^3

TOTAL GAS CONTENT: 6.38 cm^3/gram or 204.2 ft^3/ton in place

Size and Weight Analysis

Screen Size	Rock(gm)	Coal(gm)	Total Weight(gm)	Percent
4	2.5	0.7	3.2	0.3
10	2.2	13.3	15.5	1.3
20	2.4	179.3	181.7	13.8
40	34.3	349.7	384.0	32.9
60	1.7	280.0	281.7	24.1
80	0.0	133.0	133.0	10.5
100	1.0	57.2	58.2	5.0
200	5.2	97.7	102.9	8.8
-200	14.0	24.0	38.0	3.3

Sample Identification: REI-GH-3, 880 ft. increment-horizontal

Sample Weight: 1,375.0 grams

Sample Weight Dry: 849.0 grams

LOST GAS: 1,740 cm^3

DESORBED GAS: 2,128 cm^3

RESIDUAL GAS: 0.0 cm^3

TOTAL GAS CONTENT: 5.43 cm^3/gram or 173.9 ft^3/ton in place

Size and Weight Analysis

Screen Size	Rock(gm)	Coal(gm)	Total Weight(gm)	Percent
4	40.7	0.0	40.7	4.8
10	29.7	0.0	29.7	3.5
20	18.2	6.0	24.2	2.9
40	13.9	55.8	69.7	8.2
60	0.9	139.1	140.0	16.5
80	1.4	135.0	136.4	16.0
100	18.6	83.7	102.3	12.1
200	4.5	213.0	217.5	25.6
-200	12.4	76.1	88.5	10.4

Sample Identification: REI-GH-3, 958 ft. increment-horizontal

Sample Weight: 1,617.5 grams

Sample Weight Dry: 973.5 grams

LOST GAS: 1,440 cm^3

DESORBED GAS: 3,382 cm^3

RESIDUAL GAS: 41 cm^3

TOTAL GAS CONTENT: 5.61 cm^3/gram or 179.5 ft^3/ton in place

Size and Weight Analysis

Screen Size	Rock(gm)	Coal(gm)	Total Weight(gm)	Percent
4	35.0	0.0	35.0	3.6
10	1.5	0.4	1.9	0.2
0.1	48.3	48.4	5.0	
40	2.7	225.0	227.7	23.4
60	1.6	275.0	276.6	28.4
80	1.0	117.9	118.9	12.2
100	0.0	53.8	53.8	5.5
200	34.1	104.4	138.5	14.2
-200	33.1	39.6	72.7	7.5

Sample Identification: REI-GH-3, 1,025 ft. increment-horizontal

Sample Weight: 1,913.0 grams

Sample Weight Dry: 1,151.0 grams

LOST GAS: 1,090 cm^3

DESORBED GAS: 3,565 cm^3

RESIDUAL GAS: 10 cm^3

TOTAL GAS CONTENT: 5.21 cm^3/gram or 134.6 ft^3/ton in place

Size and Weight Analysis

Screen Size	Rock(gm)	Coal(gm)	Total Weight(gm)	Percent
4	18.1	0.0	18.1	1.6
10	3.0	0.6	3.6	0.3
20	15.2	43.9	59.1	5.1
40	5.5	290.0	295.5	25.7
60	1.6	380.0	381.6	33.1
80	0.0	150.8	150.8	13.1
100	0.0	63.3	63.3	5.5
200	0.0	136.7	136.7	11.9
-200	0.0	42.3	42.3	3.7

Sample Identification: REI-GH-3, 1,100 ft. increment-horizontal

Sample Weight: 1,887.0 grams

Sample Weight Dry: 1,198.0 grams

LOST GAS: 1,250 cm^3

DESORBED GAS: 5,963 cm^3

RESIDUAL GAS: 30 cm^3

TOTAL GAS CONTENT: 6.36 cm^3/gram or 203.6 ft^3/ton in place

Size and Weight Analysis

Screen Size	Rock(gm)	Coal(gm)	Total Weight(gm)	Percent
4	4.9	0.1	5.0	0.4
10	2.7	5.6	8.3	0.7
20	0.9	178.5	179.4	15.0
40	22.7	434.3	457.0	38.1
60	15.9	223.8	239.7	20.0
80	0.2	113.0	113.2	9.4
100	0.8	48.0	48.8	4.1
200	7.3	106.1	113.4	9.5
-200	5.5	27.7	33.2	2.8

Sample Identification: REI-GH-3, 1,185 ft increment-horizontal

Sample Weight: 1,526.5 grams

Sample Weight Dry: 953.5 grams

LOST GAS: 1,005 cm^3

DESORBED GAS: 3,093 cm^3

RESIDUAL GAS: 23 cm^3

TOTAL GAS CONTENT: 4.78 cm^3/gram or 152.8 ft^3/ton in place

Size and Weight Analysis

Screen Size	Rock(gm)	Coal(gm)	Total Weight(gm)	Percent
4	0.9	0.2	1.1	0.1
10	1.3	0.9	2.2	0.2
20	2.5	46.1	48.6	5.1
40	23.2	198.8	222.0	23.3
60	13.7	285.6	299.3	31.4
80	3.8	120.0	123.8	13.0
100	9.2	42.5	51.7	5.4
200	20.7	118.1	138.8	14.5
-200	17.7	48.3	66.0	7.0

Sample Identification: REI-GH-3, 1,255 ft. increment-horizontal

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Sample Weight: 1,535 grams

Sample Weight Dry: 956.0 grams

LOST GAS: 920 cm^3

DESORBED GAS: 3,047 cm^3

RESIDUAL GAS: 50 cm^3

TOTAL GAS CONTENT: 4.50 cm^3/gram or 144.0 ft^3/ton in place

Size and Weight Analysis

Screen Size	Rock(gm)	Coal(gm)	Total Weight(gm)	Percent
4	0.4	0.0	0.4	0.0
10	0.9	0.2	1.1	0.1
20	2.4	38.9	41.3	4.3
40	2.9	330.0	332.9	34.8
60	2.0	280.8	282.8	29.9
80	1.3	108.0	109.3	11.4
100	12.5	34.2	46.7	4.8
200	24.3	80.3	104.6	10.9
-200	18.4	18.5	36.9	3.8

IN-MINE/SURFACE MAPPING

The average residual gas content for the northern part of the Book Cliffs Coal Field is 0.86 cm^3/gram with a 0 - 3.23 cm^3/gram range whereas the Wasatch Plateau and Emery Coal Fields have average residual gas contents of 0.09 cm^3/gram and 0.02 cm^3/gram respectively. The same low residual gas values hold for the Sego Field and also others where few samples have been collected.

Because of the residual gas phenomena and the fact that all moderately gassy to gassy (total volume) coal is located in the northern part of the Book Cliffs, geologic investigative efforts have been concentrated in that region.

The following work has been accomplished and/or is in the process of being accomplished:

1. The Price River No.3 (Hardscrabble Canyon No. 3 is the title the mine owners prefer) was studied and mapped in an effort to establish and understand the geologic factors which affect the mine roof and to analyze the general characteristics of the coal bed for possible relationships to gas content. An attempt to project mine roof condition into future mining areas and to analyze the coal bed both megascopically and microscopically has been made. This study was accomplished by Mark Bunnell while working on the grant and will be

used as the basis for his thesis at Brigham Young University at a future date. The text of the report is included as Appendix A. Maps & drawings will be forwarded when complete as addenda to the appendix. This study has been submitted to the Utah Geological and Mineral Survey Publication Review Board for possible publication.

2. The text of a mapping thesis, The Geology of the Deadman Canyon 7 1/2 Minute Quadrangle, Carbon County,Utah, is submitted as Appendix B. Maps and drawings will be forwarded when complete as addenda to the appendix. This thesis has been submitted to the Utah Geological and Mineral Survey Publication Review Board and will be published as a non-colored geologic map with a condensation of the text.

OUTSTANDING CONTRACT DELIVERIBLES

1. Geologic maps of the Standardville, Helper, and Jump Creek 7 1/2 Minute Quadrangles, Carbon County, Utah to be submitted by 31 October 1983 and texts by 1 April 1984. These will be forwarded as addenda to this report upon receipt. They will also be submitted to the Utah Geological and Mineral Survey Publication Review Board for publication of maps and condensed texts.

2. A coal volume, "Observations and Analysis of Gas Content and Maceral Analysis of Collected Coal Core Samples from the Emery, Wasatch, and Book Cliffs Coal Fields", is being authored by this writer using primarily the data in this report, and other pertinent literature. This report should be forwarded in rough draft during the first week in October.

3. The Vernal Coal Field or Ute Indian data and all other data collected and evaluated between now and 30 September 1983 will be forwarded as addenda to this report.

APPENDIX A.

ROOF GEOLOGY AND COAL SEAM CHARACTERISTICS

OF THE HARDSCRABBLE CANYON NO. 3

MINE, CARBON COUNTY, UTAH

Mark Bunnell

INTRODUCTION

During mining in the Hardscrabble Canyon No. 3 Mine, in Carbon County, Utah occasional unstable roof conditions have been encountered which at times have slowed mine production, and more importantly, have presented a safety hazard to mine personnel. This problem of roof control, coupled with other mining problems related to the geologic setting of the mine area, created the need for an in-mine geologic analysis of the mine roof as well as the mined coal seam.

This study was undertaken in an effort to establish and understand the geologic factors which affect the mine roof, and to analyze the general and gas characteristics of the coal bed. An attempt has also been made to project mine roof conditions into proposed future mining areas, and to analyze the coal both megascopically and microscopically. With the present increased interest in efficient, safe, and cost effective coal development, an understanding of the geologic parameters that affect coal and coal mining in the area is vital.

Coal being mined in the Hardscrabble No. 3 Mine is in the Sub-3 seam of coal, the lowest coal bed of the Spring Canyon coal group in the Upper Cretaceous Blackhawk Formation. The Spring Canyon coal group is the basal coal group of the exposed Blackhawk Formation in the mine area, and is underlain by a thick marine sandstone unit. This massive sandstone is part of the basal Spring Canyon sandstone tongue of the Blackhawk Formation.

Regionally, the Sub-3 seam is reported to range in thickness from 20cm (8 in) in western surface exposures (sec. 8, T 13 S, R 9 E) to 2.2 m (7 ft, 4 in) in eastern exposures (sec. 11, T 13 S, R 9 E). The seam reaches a maximum thickness of slightly over 3 m in Hardscrabble Canyon and in Spring Canyon 1928). Within the projected mine area, the seam, including 1 to 3 thin splits, is over 3 m (10 ft), but thins eastward and westward to less than 1.2 m (4 ft) (unpublished mine data). Rocks immediately overlying the Sub-3 seam vary from fine-grained sandstone to siltstone and shale. As early as 1932, it was reported that the Sub-3 seam exhibited a great variety of roof rocks (Tomlinson, 1932).

Field work for this study was begun in April of 1981, and completed in October of 1981. Lab work began in October of 1981 and continued through December of 1981.

LOCATION AND ACCESS

The main portal of the No. 3 Mine is located in Hardscrabble Canyon, about 2 km northwest of Helper, Carbon County, Utah (Fig.1). The mine area is located in sections 33, 34, and 35, of T. 12 S., R. 9 E.; and in sections 2, 3, and 10 of T. 13 S., R. 9 E. The portal is easily accessible by means of a paved road which connects to U.S. Highway 50 and 6 about 1 km northwest of Helper.

PURPOSE OF INVESTIGATION

In the past, the coal industry used geology primarily for exploration and delineation of coal tracts prior to mining, but when it came to mine planning and mine development, the science played a relatively minor role. With increased demands for efficient and cost-effective coal extraction, however, an understanding of the geology, gas content, depositional environments, and contemporaneous tectonic influences of coal bodies is crucial. Exploratory coal drilling can provide coal companies with a very limited idea of roof conditions, gas content, and coal characteristics in a proposed mining area, but it cannot be used to map local, yet relevant, lithologic or coal quality patterns only a few meters to tens of meters in lateral extent. These local irregularities, however, commonly have the greatest influence on roof stability and local changes in coal quality and recoverability.

As mentioned previously, production in the Hardscrabble No. 3 Mine has occasionally been hampered by such localized irregularities. Sudden local variations in roof stability occur, as well as localized coal bed discontinuities. For this reason, in-mine geologic analyses of the roof and coal are vital in order to gain an understanding of why these local changes occur, where they occur, and what effect geologic parameters of the mine area have on roof and coal conditions.

The purposes of this study are: 1) to map roof lithology and to delineate and describe the depositional environments evidenced in rocks exposed in the mine roof; 2) to relate the roof geology to existing mine roof conditions and project expected roof conditions into proposed mine development areas; 3) to study the megascopic charactersitics of the coal seam, including such characteristics as banding, methane content, cleat, rock interbeds, and coal seam discontinuities; and 4) to make a brief petrographic analysis of the coal and relate it to megascopic characteristics of the seam. This study should provide a signficant addition to the existing geologic data base of the No. 3 Mine, as well as provide insights into the geologic considerations of coal mine roof conditions and coal seam charactertistics of the area.

PREVIOUS WORK

Although several broad studies of the coal geology and stratigraphy of various Utah coal fields have been made, the number of geologic studies of individual coal mines or coal seams is limited. Such studies are commonly relatively brief and limited to one or two charactertistics of a mine or seam. In the United States, most detailed studies of coal mine roof geology and coal seam characteristics have been conducted in eastern coal mines. Many of these have been successful in predicting roof and coal conditions in advance of mining.

Taff (1905) was one of the earliest workers in the Book Cliffs Coal Field, of which the Hardscrabble Canyon area is a part. His study consisted of a brief reconnaissance survey of the Book Cliffs Coal Field. In 1925, Spieker and Reeside named the coal-bearing Blackhawk Formation, with its designated type section near what was called the Blackhawk Mine near Hiawatha, Utah. The first extensive work that included the Spring Canyon coal group was done by Clark (1928). He gave surface exposure thicknesses for the Sub-3 seam and described lithology, stratigraphic relationships, and coal quality of the Spring Canyon coal group. Spieker (1931) correlated what is now called the Sub-3 seam with the Hiawatha seam of the Wasatch Plateau Coal Field. Young (1955, 1957, 1966, and 1976) has delineated the stratigraphy, sedimentary facies, and facies relationships of the Book Cliffs Coal Field. Doelling (1972), in a quadrangle-by-quadrangle approach to the coal fields of Utah, described the general characteristics of the Sub-3 seam in the Hardscrabble Canyon area as part of his description of coal in the Castlegate-Kyune quadrangle. Depositional models for the Blackhawk Formation in the Book Cliffs area of eastern Utah are discussed in a study by Balsley (1980). He also treated the effects of various depositional environments on coal deposits in the area. In a recent study by Mercier, et al. (1982), the Spring Canyon coal zone is correlated to the Hiawatha seam to the south.

Only limited individual studies of the No. 3 Mine or the Sub-3 seam have been made. Tomlinson (1932) observed roof conditions in coal mines in the Sub-3 seam and noticed not only a great variety of roof lithologies, but a tendency for hazardous roof conditions to exist in the mines as well. McCulloch and others, (1979) studied cleat orientations in the No. 3 Mine and found that the butt cleat is roughly parallel to the axial trend of a nearby anticline. Doelling, and others, (1979) gave methane desorption data and proximate analyses for the Sub-3 seam from samples taken within the No. 3 Mine area.

Other work includes studies not directly related to the Sub-3 seam or the Hardscrabble Canyon No. 3 Mine, but similar to this study one, of coal characteristics and mine roof geology in other coal mines. Howard (1972) indicated some of the possible effects of channel-fill sandstone bodies on coal and mine roof conditions in the Book Cliffs Coal Field near Sunnyside, Utah. His observations were limited, however, to outcrop and drill-hole information, and no actual in-mine observations were conducted. The first detailed in-mine analysis of effects of geologic conditions on coal mining in east-central Utah area was conducted by Mercier and Lloyd (1981) in two coal mines in the Wasatch Plateau Coal Field, about 50 km south of the No. 3 Mine. They found that mine roof lithologies had a profound effect on overall roof conditions in the two mines, and that many roof failures occur at the boundaries of channel-fill sandstone bodies with overbank/interchannel deposits. Several coal mining companies in the eastern and central Utah area have recently started programs of in-mine geologic analysis.

Numerous workers in coal fields of the eastern United States, including McCulloch and Deul (1973), Overbay, and others, (1973), Ferm and Melton (1975), Horne, and others, (1978), McCabe and Pascoe (1978), and Krausse, and others, (1979), have studied the effects of roof lithology and other geologic parameters on coal and coal mine conditions. Although these studies were conducted in other regions and the depositional settings may differ to varying degrees, the principles which were applied and the types of observations which were made have been valuable guides for data accumulation and interpretation during the present study.

PRESENT STUDY

The present study is a result of a continuing program of coal and coal mine analysis sponsored by the Utah Geological and Mineral Survey in Utah coal fields. Some of the data used in this study were supplied by the mining company, including data from numerous drill holes and information from confidential mine studies.

METHODS OF STUDY

This study was conducted in four phases. Two phases involved in-mine analysis, whereas the other two phases involved the gathering and interpretation of drill hole data and petrographic analysis of roof rocks, as well as the coal seam.

The first phase involved detailed mapping of mine roof lithology and characteristics in all accessible areas of the coal mine. Mapping was done on a 1:1,200 scale on existing maps supplied by the company. Lithologic boundaries exposed in the immediate mine roof, as well as other features such a roof falls and clastic dikes, were plotted on mine entries and crosscuts, and then projected across coal pillars. Paleocurrent orientations on exposed sedimentary structures were also measured and plotted during this phase.

Phase two was initiated upon completion of phase one, and involved measurement of 73 stratigraphic section at selected locations within the mine. Sections were measured at approximately 30 to 35 m intervals (on each coal pillar) in three areas to determine the lateral continuity of various coal seam characteristics. Once lateral continuity was established, other sections were measured at more widely spaced locations within the mine to allow complete seam analysis over the entire available mine area. Coal thickness as well as thicknesses of lithotype bands within the seam were measures, and lithotype bands were identified and described in detail. During this phase, roof rock samples, as well as channel and column samples of the coal seam were taken for petrographic analysis. Numerous mine gas samples were also obtained during this phase.

Phase three consisted of an analysis of 59 drill holes in the proposed mine area. Coal seam charactertistics were studied, along with immediate roof lithology. From information gathered during this phase, an isosand map of the proposed mining area was produced. Isopach and interburden maps were also utilized in this phase to aid in the preparation of the isosand maps.

Phase four consisted of preparation and analysis of roof rock thin sections and polished coal columns and pellets. Eight thin sections were prepared from various roof lithologies and analyzed petrographically for a general understanding of the nature and composition of various types of roof strata. Two polished coal columns were prepared and analyzed microscopically to determine percentages of microlithotypes within each megascopic lithotype band. Polished coal pellets were also prepared, from which information regarding maceral content and vitrinite reflectance were obtained. Proximate and ultimate analyses were also run on two channel samples of the coal seam.

GENERAL GEOLOGY

The Hardscrabble Canyon No. 3 Mine is located in the northwest portion of the Colorado Plateau and in the northwestern end of the Book Cliffs of east -central Utah. The rocks in the mine area consist entirely of Upper Cretaceous sedimentary rocks that dip gently to the northeast.

STRATIGRAPHY

Exposed rocks of the immediate mine area include part of all of four Upper Cretaceous Formations, from the base up the Mancos Shale, Starpoint Sandstone, Blackhawk Formation, and Price River Formation (Fig. 2). These units form cliffs and ledges separated by slopes with variations produced by differences in erosion rates. Sandstones commonly form ledges and cliffs, while less resistant siltstone, shale, and coal seams form the intervening slopes.

Mancos Shale

The Mancos Shale, named by Cross (1899), forms a broad slope at the base of the Book Cliffs, as well as rounded hills and steep badland cliffs in the Hardscrabble No. 3 Mine area. It consists mainly of gray to bluish-gray to drab marine shale with occasional interbeds of sandstone and minor limestone. Only the uppermost portion of the Mancos is exposed in the area, and it grades upward into, and interfingers westward with, two marine sandstone tongues of the Star Point Sandstone. Rocks at the contact between Mancos Shale and overlying tongues of the Star Point are reported to be early Campanian (Young, 1966).

About 300 m of the upper Mancos Shale are exposed in the area and have been identified as uppermost Masuk Member by Young (1955 and 1966). A westward-thinning tongue of the Mancos Shale overlies the lowermost tongue of the Star Point Sandstone. This represents only one in a whole series of regional intertonguing clastic wedges that occur in the contact zone of the Mancos Shale with the Star Point Sandstone of the Mesaverde Group.

Star Point Sandstone

The Star Point Sandstone was named by Spieker and Reeside (1925) and is the lowest formation in the Mesaverde Group in the No. 3 Mine area. It is a prominent cliff former and consists of two eastward-pointing sandstone tongues of medial Campanian age. The basal sandstone tongue is the Panther Sandstone and the upper tongue is the Storrs Sandstone (Young, 1955). The Panther Sandstone is 30 to 40 m thick in the mine area, and the Storrs Sandstone tongue is about 5 to 10 m thick. About 40 m of Mancos Shale separates the two units.

The Panther Sandstone has been studied in great detail by Howard (1966). It consists of shale at the base and grades upward into beds of massive, well--indurated, crossbedded marine sandstone. The Storrs Sandstone consists of shale at the base which grades upward into beds of soft, friable sandstone. In the Helper, Utah area, the top of the Star Point Sandstone was placed at the top of the Storrs tongue by Young (1955), who recommended lowering the formation boundary to exclude the overlying Spring Canyon Sandstone tongue, originally included in the formation by Spieker and Reeside (1925). Mercier, and others, (1982) recently proposed that the Panther and Storrs tongues of the Star Point Sandstone be included in the basal portion of the Blackhawk Formation because of the fact that coal beds occur above each of these units in certain areas of the Wasatch Plateau.

Blackhawk Formation

The Blackhawk Formation, named by Spieker and Reeside (1925), includes the major coal-bearing rocks exposed in the Western Book Cliffs and the eastern front of the Wasatch Plateau. In Spring Canyon, just south of the Hardscrabble No. 3 Mine, the Blackhawk consists of about 3200 m of sandstone, shale, and coal (Young, 1955). Spieker and Reeside (1925) orignally placed the lower boundary of the Blackhawk at the base of the lowest coalbed exposed in the Book Cliffs and the Wasatch Plateau, which is the base of the Sub-3 seam in the mine area. However, Young (1955) as previously mentioned, lowered the formation to the base of the Spring Canyon Sandstone tongue of Clark (1928). The upper boundary of the Blackhawk Formation is disconformable, and is mapped at the base of the Castlegate Sandstone. Blackhawk rocks overlie the Star Point, but are still of medial Campanian age (Spieker, 1931).

Regionally, the time-transgressive base of the Blackhawk Formation consists of six prominent littoral marine sandstone tongues, as well as many lesser ones, all projecting eastward into the Mancos Shale, where they lose their identity by grading into shale (Young, 1955). In the mine area, as mentioned previously, the basal sandstone tongue of the Blackhawk is the Spring Canyon Sandstone tongue. The Spring Canyon Sandstone tongue (about 50 m thick in the mine area), along with 20 to 30 m of overlying coal-bearing shale and sandstone, form the Spring Canyon Member of the Blackhawk. The coals within this member are known as the Spring Canyon Coal Group (Clark, 1928). The Sub-3 seam, in which the Hardscrabble Canyon No. 3 Mine is mining, is the lowest of three major coal beds in the Spring Canyon Coal Group. Clark (1928) and Spieker (1931) originally correlated the Sub-3 seam to the Hiawatha seam, a major coal that directly overlies the Spring Canyon Sandstone tongue in the Wasatch Plateau to the south. Mercier, and others, (1982) also indicate that the two coals may indeed be correlative.

Directly overlying the Spring Canyon Member is the Aberdeen Member which includes the basal Aberdeen Sandstone and overlying coal-bearing sandstone and shale (Young, 1955). The lower sandstone tongue is about 26 m thick, and the overlying interbedded part of the member is 30 m thick in the Kenilworth area to the east. In the Hardscrabble Canyon area, however, the upper interbedded part of the member has no well-defined top and is included in the overlying 290 m of undifferentiated coal-bearing strata (Young, 1955).

As mentioned previously, the Sub-3 seam is immediately underlain by the Spring Canyon Sandstone tongue which makes an excellent floor rock for the No. 3 Mine. The strata immediately overlying the Sub-3 seam consist of interbedded sandstone, siltstone, shale, and coal. The bedding relationships of these strata have a profound effect on No. 3 Mine roof conditions.

Spieker and Reeside (1925) interpreted the general depositional setting of the Blackhawk Formation to be a broad coastal plain. Later studies by Young (1955, 1957, 1966, and 1976) and Howard (1972) indicated that the sandstone sheets or tongues represent barrier islands. Balsley (1980) cited evidence to suggest that most of the sheet sands were deposited by wave-dominated deltas, upon which the major coal beds developed.

Price River Formation

Spieker and Reeside (1925) separated a series of noncoal-bearing beds above the Blackhawk Formation as the Price River Formation. The latter unit is the upper part of the Mesaverde Group (Clark, 1928). In the vicinity of the Hardscrabble Canyon No. 3 Mine, the formation consists of the massive basal Castlegate Sandstone Member, and overlying lenticular interbedded shale, siltstone, and sandstone. The Castlegate Sandstone Member forms a vertical cliff about 150 m high, while overlying sandstone and shale units form ledges and slopes. The Price River Formation is approximately 400 m thick near the No. 3 Mine (Abbott and Liscomb, 1956) and is Campanian and Maestrichtian (Cobban and Reeside, 1952). The Price River Formation lies disconformably upon Blackhawk beds in the mine area.

STRUCTURE

The area around the Hardscrabble Canyon No. 3 Mine lies in the region of a gentle north to northwestward dipping homoclinal structure of the Book Cliffs. Rocks in the mine area, including the Sub-3 seam, generally dip 4 to 6 degrees to the northwest. Only a few faults occur in the general area, and these are 5 to 6 km west of the mine. They are relatively minor normal faults with maximum throws of about 7 m.

No faults have been encountered in the No. 3 Mine and none are apparent in the projected mine area. One low anticline occurs northwest of Hardscrabble Canyon and a shallow syncline occurs northeast of the canyon (Doelling, 1972). For the most part, starta in the immediate mine area indicate structural stability and, thus, no major structural problems are expected to be encountered during future mine development.

MINING OPERATION

Mining in the Hardscrabble Canyon No. 3 Mine has consisted of both room and pillar and longwall mining methods. Room and pillar extraction was the main method used until about seven years ago, when Longwall mining was initiated. Presently, only "continuous miners" are being used for both development and production mining in room and pillar extraction. Coal is carried out of the mine on conveyor belt systems. In general, geologic conditions have played, and continue to play, a significant role in the efficiency and effectiveness of both of these extraction methods.

The mine portal is located on the north side of Hardscrabble Canyon. Work is presently underway on two vertical shafts in Crandall Canyon, to the north. One of these shafts will be used for transport of equipment and personnel. The mine workings generally underlie rather rugged topography, with overburden depths ranging abruptly from about 730 m to less than 180 m beneath the numerous steep-sided canyons and intervening ridges.

ROOF GEOLOGY

Lithology and stratification of beds immediately overlying the Sub-3 seam vary greatly in the Hardscrabble Canyon No. 3 Mine, largely produced by rapid lateral changes from one depositional setting to another. Because rocks of each of these depositional environments affect the mine roof somewhat differently, roof conditions may vary significantly in relatively short distances. Tomlinson (1932, p____) noted that the greatest variety of roof conditions (at that time) above any Utah coal seams were those above the Sub-3 seam. He described the roof lithologies as varying from fine-grained sandstone to sandy--shale and shale, and observed that the roof is extremely treacherous. Abrupt variations in mine roof stability are still common above the Sub-3 seam, creating hazards for mine personnel, as well as hampering production and increasing mining expense.

Numerous factors contribute to roof instability during coal mining. In the past, the most commonly studied factors related to roof stability have been such factors as mining technique, mining sequence, mine orientation, entry width, pillar size, roof bolting technique, depth of mining, and roof hydrology. An understanding of such factors, indeed, is crucial to maintaining a stable roof. Only recently have detailed studies been made of geologic characteristics of immediate mine roof strata. In fact, it has been only during the last 5 to 10 years that coal mining companies in Utah have initiated programs of detailed analysis of roof geology. The present study is designed to fill this need in the No. 3 Mine, where an understanding of existing roof lithology is important for maximum efficiency of mine roof control.

Lithology of the immediate mine roof (the 3 m interval above the coal seam) in the Hardscrabble No. 3 Mine varies from siltstone to very fine-grained sandstone, with minor interbeds of mudstone, carbonaceous mudstone, and coal. Detailed mapping of exposed roof rocks differentiates 3 major facies within a floodplain environment. These facies include channel-fill sandstone deposits, overbank deposits of sandstone, siltstone, and minor mudstone, and swamp deposits of carbonaceous mudstone and coal. These floodplain environments represent only a minor part of the overall environment in which

Basal surfaces of channel-fill sandstone in the mine roof are readily differentiable from the other facies by their charactertistic lateral discontinuity, convex-down shape, undulating basal surface, content of rip-up clasts of siltstone or coal, and occasional well-developed flute casts and tool marks. Trough cross-bed sets are evident in the interior of the channel sandstone bodies but do not occur in either of the other facies.

Five thin sections of fluvial channel sandstone were made from samples taken at various localities. Thin section analyses indicate that the grain sizes range from very fine to fine-grained sand with a calcite cement. Sand grains range from subangular to rounded, with subrounded grains dominating. General size distribution of grains in each of the samples is shown in Table 1.

Table 1. Grain size distribution in fluvial channel samples.

Sample No	500-250	250-125	125-62	62-31	31-16	Number of grains counted
1	2	43	50	5	0	100
2	2	47	38	13	0	100
3	0	23	61	15	1	100
4	0	11	70	18	1	100
5	1	18	59	22	0	100

The 250 to 62 grain size dominates, with grains falling in the 62 to 31 size range also making up a substantial part of most samples. Cumulative frequency curves for the five samples indicate their general similarities (Fig. 4). All of the samples are well sorted and relatively clean, with some clay included in the caclite. It was not possible through in-mine observation of texture or through thin-section analysis to find obvious differences between different channel-fill sandstone bodies. Each appears to have had the same source and to have been deposited in about the same energy regime.

Paleocurrent directions in the channel-fill bodies are dominantly northeast to southeast (Fig. 3). Flow directions were readily determined from trough cross-bed sets, flute casts, and ripple marks. These flow directions generally appear to coincide with those obtained by other workers in the Wasatch Plateau and the Book Cliffs Coal Fields. Mercier and Lloyd (1981) indicate a general northeasterly paleocurrent direction for sandstone mapped above the Hiawatha seam, in the Wilberg Mine, and for those above the Blind Canyon seam, above the Deer Creek Mine. Both of these mines are south of the Hardscrabble No. 3 Mine. The author has studied channel-fill sandstone bodies above the Castelgate D seam that exhibit an east to southeast flow direction. In general, a western source is indicated for many channel-fill sandstones of the Blackhawk Formation and those above the Sub-3 seam are no exception.

For the most part, channel-fill sandstone bodies exhibit excellent roof conditions locally, especially when they are in direct contact with the coal seam and form the entire bolted roof. The paleochannel sandstones are generally massive and are not subject to delamination and deterioration. They are commonly only slightly jointed or non-jointed. However, numerous roof falls have occurred in the paleochannel bodies (Fig. 3), along thin mudstone laminae which were highly slickensided during differential compaction. In some cases large blocks of these sandstone bodies have fallen, bringing down numerous rows of roof bolts.

The most hazardous roof conditions associated with sandstone bodies in the No 3 Mine, occur where the sandstone is not in direct contact with the coal seam, but where the sandstone occurs in the mine roof from 20 cm to 2 m above the seam, and siltstone separates the coal and the paleochannel fill. In these areas, differential compaction of the brittle siltstone appears to have created stress within the siltstone, and as mining proceeds beneath the paleochannel, residual stress release fractures form. Roof conditions generally worsen dramatically after several days and large blocks and slabs of siltstone begin separating from the sandstone body in sections between roof bolts. Concentric, parallel fractures occur in the differentially compacted zones beneath the channel-fill bodies in the No. 3 Mine, as compared with the highly slickensided, irregular fractures in mudstones above other coal seams in the region (Mercier and Lloyd, 1980). The fracture zones beneath the channel-fill bodies of the No. 3 Mine are also relatively narrow, generally less than 20 m wide.

During deposition, streams above the Sub-3 seam rarely had enough energy to scour through the layer of silt and into the peat. It is common for channel-fill bodies to rest directly upon the coal seam, but seldom do any of them actually scour into the coal. Where scour is evident, generally only 5 cm to 1 m of coal are missing, and even this erosion is very local. The peat, apparently due to the matted organic texture, was very resistant to channel scour. Major channel scours or "washouts" of portions of entire coal seams are known to occur in area coal mines. However, it is believed that such "washout" zones represent a much higher energy channel-fill deposit than is generally encountered in the Hardscrabble No. 3 Mine.

Another notable feature of these channel-fill sandstone bodies is that many of them are located above large coal seam "rolls" or undulations of the coal bed and the enclosing strata. A roll is a local miner's term for a localized downward or upward steepening of the dip of a coal seam. A typical roll in the No. 3 Mine consists of a sudden steepening of the dip of the seam from 4 or 5 degrees to as much as 8 to 10 degrees within a lateral distance of 3 to 6 m. Within 20 to 30 m, the dip of the seam returns to its original dip and either maintains that orientation or dips upward slightly for another 20 to 30 m (Fig. 5). Many of the larger channel-fill bodies in the No. 3 Mine appear to follow roughly the same trends as the rolls. It has not been ascertained whether the paleochannels follow paleotopographic features which we now observe as a roll, or whether the rolls are the result of differential compaction beneath the lenticular channel-fill sandstone bodies. A discussion of this question is included later in this report in a special section on coal seam rolls.

Ground water is another common feature associated with channel-fill bodies. Where seeps were encountered in the mine there was almost invariably a sandstone channel in the roof. Water from these sand bodies does not appear to be of major concern to mining in the No. 3 Mine; although, where it does occur, it may contribute to the weakening of the immediate roof strata.

In general, channel-fill sandstone bodies can be recognized in the mine roof by the following characteristics:

1. They are composed of clean, calcareous, very fine to fine-grained quartz sandstone.
2. They exhibit a convex down base with numerous small, rounded undulations, and in many instances, flute casts.
3. Trough cross-bed sets and lenticular bedding are common, with occasional ripple marks.

4. A zone of concentrically fractured siltstone occurs in the differentially compacted zone immediately beneath the sand body, creating unstable roof conditions.
5. An increase in water dripping from the roof is common, either directly from an exposed sandstone body or through the underlyling fractured siltstone layer.
6. The coal seam may occasionally be scoured and/or compacted.
7. A coal seam roll may occur immediately beneath the channel-fill sandstone body.

Overbank Facies

Overbank deposits are common in the roof of the No. 3 Mine, and, in fact, cover the greatest area of any of the exposed roof lithologies. The overbank facies consist mainly of siltstone, sandstone, and occasional mudstone interbeds.

By far the most common lighology of the overbank facies is the siltstone "caprock" that immediately overlies the Sub-3 seam virtually throughout the No. 3 Mine. The caprock is over 3 m thick in many areas of the mine, and forms an excellent stable roof when thin interbeds of overbank sandstone or paleochannel sandstone bodies are not present. The siltstone was apparently deposited over the entire mined portion of the Sub-3 seam prior to the migration of paleochannels across the area. It is likely that the siltstone represents overbank deposition from a nearby major fluvial system, which developed immediately after peat deposition and probably caused the cessation of peat production.

The overbank siltstone is generally unfossiliferous, with only one thin band of fossil bivalves and gastropods occurring about 3 m above the seam. This fossil zone is observable only in larger roof falls. The siltstone is only slightly carbonaceous and is, for the most part, clean, hard, and brittle. As mentioned earlier, it has the tendency to form concentric, parallel fractures spaced from 3 to 20 cm apart when compacted. Where such fractures occur, hazardous roof conditions may exist, and the roof can be difficult to stabilize.

Of the various roof lithologies present in the Hardscrabble No. 3 Mine, overbank deposits of thinly bedded sandstone create the most treacherous roof conditions, particularly where the total overburden approaches or exceeds 600 m. These thin-bedded sand deposits generally accumulated along flanks of channel-fill sand bodies and, in certain instances, formed broad sheet sands of considerable lateral extent (Fig. 3). It is possible that these sheetlike sandstones represent a combination of levee and splay overbank deposition from numerous small fluvial channels that exist in the mine roof.

These thin-bedded deposits range from about 10 cm to over 2 m thick, where observed in roof falls and overcasts. Individual sandstone beds range from about 4 cm to 20 cm thick, with occasional interlamination of siltstone and mudstone. The thin sandstone beds are commonly ripple laminated and, in many cases, climbing ripples are present, indicating rapid deposition. The sandstone of these overbank deposits is very fine-grained, well sorted, moderately indurated, with a calcite cement. In general, grain composition of these sands is similar to the paleochannel sandstone bodies. Grain size, however, appears to be slightly finer.

Thin section analysis of samples from overbank sandstones show that they are composed almost entirely of quartz, and that grains range from very fine to fine-grained, with the very fine-grained proportion dominating. Calcite forms the cement, with some clay and carbonaceous material included. A total of 3 samples were obtained for thin-section analysis, and the general grain-size characteristics of the samples are tabulated in table 2.

Table 2. Grain size distribution of overbank sandstone samples.

Sample No	500-250	250-125	125-62	62-31	31-16	Number of grains counted
1	0	15	53	31	1	100
2	0	43	51	4	0	100
3	0	25	56	36	3	100

The 250-31 grain size dominates; and cumulative frequency curves of the samples show their similarities (Fig. 6). All of the samples are well sorted.

Paleocurrent directions in the overbank sandstone deposits are most commonly in a direction away from adjacent paleochannel sandstone bodies. This suggests that thin-bedded sandstone units most likely had their source in the fluvial channels and were dpeosited as splays of overbank flooding from the channel. Flow directions were readily determined from well-preserved ripple marks. Bioturbation is also common at the base of the thin-bedded sandstone layers, particularly at the contact of the overbank sandstone with the underlying overbank siltstone.

It is uncertain, due to the limitations of in-mine observation, whether the deposits represent levees or splays. Well-developed levee deposits are poorly known, or, at least, are not well documented in the lower portion of the Blackhawk Formation in the mine area. Moebs and Ellenberger (1982) use the term "crevasse splay" in a nongenetic descriptive sense, for thinly bedded sandstone deposits found in Appalachian coal mines. They describe these units as ranging from 2 to 9.3 m thick, laterally persistent, and sheetlike to lenticular. They are comprised of predominantly flat-bedded, laminated sandstone, interbedded with shale. When these "crevasse splay" units lie within 2 to 3 m of the top of the coal bed, the mine roof may be adversely affected due to inherent weakness along the contact of the shale and sandstone laminae. A similar condition appears to exist with the overbank sandstone deposits above the Hardscrabble No. 3 Mine.

As mentioned previously, some of the most hazardous roof conditions in the No. 3 Mine are produced by overbank sandstone deposits. The thinly bedded sandstone appears to delaminate and sag rather readily, and eventually fall, in many cases bringing down the entire bolted interval of rock. Overbank sandstone deposits, like the fluvial channel-fill bodies, are usually separated from the underlying coal seam by the overbank siltstone layer. This brittle siltstone commonly begins to fracture during initial phases of roof sagging, and within several days, large slabs of overbank siltstone and sandstone begin falling, usually without warning.

Overbank sandstone deposits may be more widespread in the mine roof than fig. 3 indicates, since the siltstone caprock may be obscurring their observation. It is believed, however, that where such overbank sandstone deposits are present in the immediate roof, the siltstone most commonly delaminates from the sandstone and falls away, exposing the sandstone. After observing roof-bolting operations in various portions of the mine, it is ap- parent that thin, isolated, layers of sandstone are quite common. However, for the most part, these layers are thinner than the better developed overbank sandstone, which originated from the fluvial channels, and do not adversely affect mine roof conditions.

In summary, the overbank deposits of the No. 3 Mine have the following characteristics:

1. The overbank deposits of siltstone generally form excellent roof conditions where they are not associated with channel-fill sandstone bodies or overbank deposits of sandstone.
2. The siltstone immediately overlies the Sub-3 seam throughout the entire mined portion, except where channel scour has occurred.
3. The overbank sandstone deposits are characterized by thin, horizontally bedded, very fine to fine-grained sandstone which may show considerable lateral continuity.
4. The thinly bedded sandstones may reach thicknesses over 2 m, and generally occur along the flanks of channel-fill sandstone bodies.
5. Ripple lamination is characteristic of the thinly bedded overbank sandstone, and bioturbation is common at the contact with the underlying siltstone.

Swamp Facies

Swamp deposits in the immediate mine roof are generally rider seams of coal and associated carbonaceous mudstone interbeds. The rider seams above the Sub-3 seam in the No. 3 Mine are 10 to 30 cm thick. These thin coal seams commonly split from the Sub-3 seam in some areas, and are separated from it by a siltstone. These siltstone layers generally thicken away from the area of initial separation, as the interval between the main seam and the rider increases. Rider seams in the No. 3 Mine above the Sub-3 seam range from a few centimeters to several meters.

Rider seams above the Sub-3 seam do not adversely affect the roof in the No. 3 Mine. This is likely because all of the observed riders are located within the roof-bolted interval, and separation can therefore not occur in the weak rider seam. Petranoff, and others, (1981) indicate a similar situation in an underground coal mine in wyoming. They found that rider seams do not adversely affect the mine roof when they are located within the roof-bolted interval. However, when they lie in the 1.8 m to 3.1 m interval above the roof bolts, adverse conditions may exist. A similar situation can likely be expected in the No. 3 Mine when rider seams are sufficiently separated from the Sub-3 seam to fall within the 1.3 m zone above the roof bolts.

ROOF FALL CLASSIFICATION AND DESCRIPTION

Roof instability in the No. 3 Mine appears to be closely related to the various depositional facies present in the mine roof. It has, in fact, been possible to classify various types of roof falls in the mine according to their occurrence in roof strata of different depositional origins. Most occurrences of unstable roof in the No. 3 Mine appear to be the result of inherent weaknesses within either the fluvial channel-fill facies or the overbank facies. Other causes of unstable roof undoubtedly exist within the mine, most of which are likely the result of stress fields induced during mining. Although the engineering-related, mining-induced, roof-stability problems are beyond the scope of this study, it should be noted that such factors, with roof geology-related factors, produce unstable roof conditions.

Four genetic types of roof falls occur within the Hardscrabble Canyon No. 3 Mine. Three are associated with specific depositonal regimes, and one appears to be unrelated to roof geology. These four roof fall types include: 1) falls associated with channel-fill sandstone bodies, 2) falls associated with overbank sandstone deposits, 3) falls associated with fracturing of overbank siltstone deposits, and 4) "cathedral" type roof falls, which appear to be unrelated to roof geology. These categories of roof falls will be referred to as Type A, B, C, and D, respectively.

Type A Roof Falls

Type A roof falls are those which occur in fluvial channel-fill sandstone deposits. Figure 3 shows the mapped locations of type A roof falls in the Hardscrabble No. 3 Mine.

Falls of this type most commonly occur as slabs and blocks which delaminate from the bases of fluvial channel sandstone bodies immediately after mining and before roof bolting takes place. Occasionally this delamination from the paleochannel base occurs over a period of time and the slabs and blocks of sandstone delaminate and fall around the roof bolts without actually pulling the bolts down (Fig. 7). Delamination occurs along highly slickensided, clay-rich laminae within the bases of the sandstone channels. These slickensides are likely created by the differential compaction of thin mudstone laminae within the channel-fill sandstone body. The slickensides are obvious zones of weakness along which large slabs and blocks delaminate and fall.

In general in the No. 3 Mine, Type A roof falls are relatively minor features, which fall almost immediately after undercutting of the coal seam during mining. This presents little danger to mine personnel, since roof bolting usually stabilizes the problem areas. As mentioned previously some delamination and deterioration may occur after roof bolting, and large slabs and blocks may fall away around the roof bolts. This situation does present a hazard to mine personnel, and, for this reason, paleochannel deposits in the roof of the No. 3 Mine should be monitored and any loose slabs and blocks should be pried down.

Type B Roof Falls

Type B falls occur in overbank sandstone deposits and are, at present, perhaps the most common and one of the most hazardous types of roof falls in the Hardscrabble No. 3 Mine. The overbank sandstone is thinly bedded and commonly contains thin laminae of siltstone and mudstone. Delamination occurs readily at lithologic boundaries, allowing large slabs of overbank sandstone to fall.

As with Type A falls, the sandstone slabs of Type B falls most commonly fall away at the time of mining, before the roof can be bolted. After the coal has been removed from beneath the overbank sandstone, the roof often begins to sag, and sandstone slabs delaminate and fall away. Occasionally, however, serious roof falls related to sagging and delamination occur after the roof has been bolted (Fig. 7). It is also not uncommon for delamination to occur above the roof-bolted interval. In this case, large slabs, up to 2 m thick, containing numerous rows of roof bolts may fall. Large falls such as these are quite unpredictable and hazardous.

It should be noted that the number of large roof falls related to overbank sandstones increases with increasing overburden thickness. A high percentage of the Type B roof falls shown in Figure 3 are located under overburden thicknesses which approach or exceed 600 m. In this situation, sagging of the roof is common and delamination occurs readily. As mentioned previously, overbank deposits undoubtedly occur in other portions of the mine, but are not visible because they have not sufficiently influenced roof conditions.

The most harardous situation related to overbank sandstone deposits occurs when the roof bolts do not extend through the entire overbank sandstone interval. When this happens, delamination can occur above the roof bolt interval and the entire bolted section can delaminate and fall. To avoid this situation, roof lithologies should be carefully mapped and measured as mining advances beneath the overbank sandstone deposits. As long as the entire overbank sandstone sequence is included within the roof-bolt interval, major Type B falls are not likely. If the overbank sandstone sequence extends above the roof bolts, additional measures should be taken to support the roof. Moebs and Ellenberger (1982) noted such occurrences in certain Appalachian area coal mines.

Type C Roof Falls

Type C roof falls occur in the overbank siltstone which immediately overlies the Sub-3 seam in the No. 3 Mine. These falls occur where residual stress release fractures develop in the siltstone due to differential compaction beneath channel-fill sandstone bodies, or where extensional fractures form due to sagging of overlying overbank sandstone beds. In both instances, closely spaced, parallel, concentric fractures form in the siltstone, and blocks of siltstone delaminate and fall away between rows of roof bolts at the siltstone/sandstone boundary (Fig. 7).

Falls of this type are relatively minor and commonly occur in combination with other roof fall types (Fig. 3). They do, nevertheless, represent an unsafe roof condition and must be closely monitored. The fractures generally form within a few days of initial mining, and roof conditions worsen until Type C roof falls begin to occur. If roof conditions are carefully monitored, unstable blocks of siltstone can be pried down. It should be noted that Type C roof falls are often the forerunner of Type A and B falls, and measures should be taken to properly stabilize such areas.

Type D Roof Falls

Type D roof falls include all falls which do not appear to be related to any specific depositional facies. These falls have a characteristic dome or "cathedral" shape and most commonly occur at mine entry intersections (Fig. 7).

The cause or causes of Type D roof falls are uncertain. Only five such falls were mapped in the mine. Those which occurred in the western portion of the mine could be related to the stresses involved in the advancement of an overlapping coal mine (Fig. 3). It appears, however, that others may be related to extreme variations in the overlying topographic relief. At any rate, the cause of Type D falls does not appear to be related to roof geology. Engineering-related study will be required to determine their exact cause.

Type D falls are extremely hazardous and are, as yet, very unpredictable. These dome-shaped falls seem to occur without warning and they commonly extend upward to over 10 m into the mine roof. No obvious fractures or indications of stress are present, and there is no correlation with roof lithology or stratification of beds. Peng (1978) indicates that roof failures such as these result from the combined effects of rock strength and stress fields induced in the vicinity of the mine entries.

PROJECTED ROOF GEOLOGY AND STABILITY

With the use of abundant drill-hole data, in combination with in-mine mapping, expected roof conditions and lithology have been projected into development areas for the No. 3 Mine. An isosand map, indicating the percent sandstone in the 0 to 3 m roof rock interval above the proposed mine area, for the No. 3 Mine, was developed by calculating the percent sandstone in the 3 meters of roof strata immediately above the Sub-3 seam as indicated in each core-hole log (Fig. 8). For the purposes of this study, 0 to 30 percent sandstone was interpreted as an overbank siltstone deposit, whereas 30 to 50 percent sandstone was interpreted to be overbank sandstone. A percentage of over 50 percent sandstone was interpreted to represent the channel-fill sandstone facies.

Although the isolith of isosand contouring is by no means an exact representation of what will actually be encountered in the No. 3 Mine, it does delineate what appear to be major depositonal trends. On that basis, some generalized projections of expected roof conditions can be made. Because most unstable roof in the Hardscrabble No. 3 Mine occurs near the paleochannel sandstone bodies or the overbank sandstone sequences flanking the channel sandstones, most of the unstable roof during future mining will likely occur in the same roof rocks. On the isosand map (Fig. 8) this would include all areas where the percentage of sandstone exceeds 30 percent. Within these areas, Types A, B, and C roof falls appear most likely to occur, and preparations should be made for careful monitoring and stabilization of these areas, if necessary.

In the areas of projected paleochannel systems, other possible geologic problems may occur in addition to unstable roof. These include such problems as paleochannel scours or "washouts, coal seam rolls, and in-flows of ground water. Paleochannel scours can cause sudden, localized thinning of a coal bed, or even complete "washout" or removal of the coal seam. Although such occurrences appear to be extremely rare in the No. 3 Mine area, they are most likely to occur in the channel-fill areas. Coal seam rolls, although they have no major effects on coal mining, do create temporary difficulties for mining machinery that must negotiate the steeper slopes. Because the paleochannel systems often act as aquifers, increased flow of water into mine entries can also be expected within the projected channel-fill areas.

In areas where less than 30 percent sandstone occurs in the projected mine roof, it is likely that stable roof conditions will exist, and no major geology-related problems should be encountered. For the most part, the No. 3 Mine has, and will continue to exhibit relatively good roof conditions. Unstable conditions will likely occur in areas which are projected to have more than 30 percent sandstone in the mine roof.

COAL SEAM CHARACTERISTICS

The Sub-3 seam is a high volatile bituminous coal, and is one of the major minable coal seams in the Hardscrabble Canyon No. 3 Mine area. A portion of this study was devoted to detailed observation of the mined coal seam, including its megascopic and microscopic characteristics. An attempt was made to determine any coal seam characteristics which may be unique to the Sub-3 seam, and to develop, if possible, a coal seam "signature."

To accomplish this, 73 stratigraphic sections were measured throughout the No. 3 Mine, and major lithotype bands within the coal bed as well as cleat characteristics and rock interbeds, were described. From this megascopic analysis, fence diagrams and coal formation graphs of lithotype banding within the coal bed were produced for the existing mine workings (Fig.s 9 and 10). Upon completion of the megascopic analysis, a microscopic analysis was conducted on polished coal columns and coal pellets from the Sub-3 seam. Two polished columns were prepared from different localities within the mine (Fig. 11), and polished coal pellets were prepared from two adjacent channel samples. The data from both the megascopic and microscopic analyses were then combined to determine if the Sub-3 seam exhibits any characteristics which give it a specific "signature," or which would serve to make it unique in any way. A determination such as this may prove important to future coal seam correlation efforts in the No. 3 Mine area, as well as provide basic information on coal quality.

MEGASCOPIC CHARACTERSTICS

Generally, the Sub-3 seam is hard, vitreous, well-banded, and well-cleated bituminous coal. Resin is common in the coal bed, especially in certain lithotype bands. Calcite is present along cleat faces and fractures, with occasional pyrite forming in dull bands. One to three thin mudstone splits or partings occur within the coal bed throughout the extent of the mine workings. Two of the most distinctive features of the Sub-3 seam within the No. 3 Mine are the well-developed lithotype bands and the well-developed cleat system. These features were studied in detail in an attempt to define particular qualities which are unique to the Sub-3 seam.

Lithotype Banding

Lithotype bands within the Sub-3 seam are well developed and laterally continuous. In order to delineate this banding, 73 stratigraphic sections were measured within the mine, and major coal lithotype bands were described. Because coal seam description can be rather subjective, the following procedure was used:

1. Detailed sections were measured at 30 m (100 ft.) intervals in certain mine entries to establish the lateral continuity of lithotype banding within the seam.
2. Once lateral continuity was established for distances up to 650 m (2000 ft.), sections were measured throughout the entire coal mine at 160 to 260 m (500 to 800 ft.) intervals.
3. The coal face at each measured section location was thoroughly cleaned to give good exposure of all lithotype bands.
4. A steel tape was secured to the coal face from roof to floor, and chalk was used to mark lithotype boundaries.
5. As suggested by Stach (1975) and Cameron (1978), all lithotype bands greater than 10 mm thick were measured and described in detail.
6. Percentages of minor lithotypes (those less than 10 mm thick) within each lithotype band were estimated with the use of charts prepared by Schopf (1960).
7. Face and butt cleat orientations were measured and described, as well as any fracture orientations in the immediate roof.
8. Roof and floor lithology was described in detail.

Although there is a certain amount of subjectivity associated with the lithotype concept, it still provides a means whereby the internal bedded structure of a coal seam can be megascopically described. Descriptions of lithotypes in the Sub-3 seam were made according to the I.C.C.P. Handbook (1963). Cameron (1978) summarized the I.C.C.P. lithotype descriptions as follows:

1. Vitrain - Very bright glassy bands or lenses, usually a few millimeters in width; thick bands are rare. Clean to the touch. In many coals, vitrain is permeated with numerous fine cracks at right angles to stratification and consequently breaks cubically, with conchoidal surfaces.
2. Clarain - Bands of variable thickness having a luster between that of vitrain and durain. Striated texture, alternation of thin bright and dull laminae.
3. Durain - Grey to brownish-black, rough surface with dull or faintly greasy luster, reflection is diffuse, markedly less fissured than vitrain.
4. Fusain - Black or grey, silky luster, fibrous structure, extreme friability.

All four of these coal lithotypes occur in the Sub-3 seam and were readily observable during section measuring.

Following megascopic description of the mined portion of the Sub-3 seam, the data were compiled and coal formation graphs were constructed according to concepts first outlined by Tasch (1960), and later by Stach (1975) (Fig. 12). The coal formation graphs, while graphically portraying lithotypes within a coal seam, also indicate the relative "wetness" of the coal swamp environment at the time of deposition. Tasch (1960) indicated that the relative degree of wetness within a coal swamp is represented by the following lithotypes and lithologies (from the driest to the wettest conditions):

1. Fusain (driest conditions)
2. Vitrain
3. Clarain
4. Durain
5. Carbonaceous Shale
6. Shale (wettest conditions)

This relative degree of wetness could also be viewed as a relative rate of subsidence within the swamp, with the driest conditions representing slow or no subsidence, and wet conditions representing more rapid subsidence. Fusain is formed at low subsidence rates and under shallow water cover, with frequent exposure to air. Shallow flooding resulted in the formation of vitrain and clarain, with deeper flooding resulting in durain (Stach, 1975). The formation of carbonaceous shale and shale would require the wettest conditions or most extensive flooding.

As can be seen in Figure 12, the formation graphs of the Sub-3 seam not only show that many lithotype bands are continuous througout the lateral extent of the mine, but alternating dry and wet conditions, or rates of subsidence, are indicated for the swamp in which the coal bed formed. These variations in swamp conditions must have occurred over a relatively broad lateral extent within the swamp, giving the Sub-3 seam a rather distinctive "signature" (at least for the lateral extent of the mined portion of the seam).

Fence diagrams of the Sub-3 seam within the entire No. 3 Mine show the laterally continuous nature of lithotype banding with the coal bed (Fig. 13). One of the notable features of the fence diagrams is the tendency for carbonaceous mudstone or mudstone partings to form only within durain bands, or during the wettest conditions. It is not uncommon for durain bands within the Sub-3 seam to grade laterally into occasional mudstone or siltstone splits or partings. In fact, the large siltstone split in the southern portion of the mine grades laterally northward into a thick durain band which continues throughout the northern extent of the mine (Fig. 13).

In general, lithotype banding within the Sub-3 seam can be characterized by a predominance of clarain and durain bands, with clarain forming the highest percentage and thickest bands. As expected in most bituminous coal seams, vitrain in the Sub-3 seam is quite abundant, but only occurs as thin lenses and laminae up to 5 mm thick, with only occasional lenses up to 15 mm thick. Because these vitrain laminae and lenses rarely exceed 10 mm in thickness and are laterally discontinuous, none of the thin vitrain bands were included in the measured sections, even though a high percentage of the seam is actually vitrain. Occasional thin lenses of fusain are also observable within the coal bed. However, as with vitrain, the fusain lenses are too thin and laterally discontinuous to be included in measured sections. These fusain lenses are commonly associated with brighter clarain bands and vitrain lenses, indicating drier swamp conditions.

Clarain bands in the Sub-3 seam can be described as midlustrous and striated, containing occasional thin lenses and laminae of vitrain and fusain. Resin commonly occurs in the bands as small blebs and as coatings along cleat faces. The striated texture of the clarain is created by alternating bright and dull laminae; the brighter laminae are composed of thin lenses of vitrain. The majority of the Sub-3 seam is comprised of clarain bands ranging from 9 to 60 cm thick. Occasional pyrite lenses and cleat fillings also occur in the clarain bands.

Durain bands in the Sub-3 seam can be described as dull and hard, containing only very few thin lenses of vitrain and clarain. Durain bands are generally thinner than many of the clarain bands within the seam, and many of the durain bands grade into carbonaceous mudstone and mudstone at some point within the seam. Resin appears to be less common and, in most cases, absent from the durain. The same is also true for pyrite which occurs only in minor amounts in durain bands in the uppermost portion of the coal seam.

Vitrain, although it is perhaps the dominant constituent of the seam, as mentioned previously, does not occur in thick enough or laterally persistent enough bands to be considered a lithotype band. Most commonly vitrain occurs as a discontinuous, thin, lenticular laminae within clarain and durain bands. These lenticular laminae usually reach a thickness of only 1 to 3 cm. The vitrain can be described as very bright and vitreous, containing numerous fine cracks or microfractures. The thicker vitrain lenses commonly exhibit a conchoidal fracture.

Fusain occurs only in minor amounts, and does not constitute a lithotype band within the seam. It occurs as lenticular laminae ranging from 1 to 3 cm thick and up to several centimeters long, occurring most commonly in clarain bands. It can be described as exhibiting a silky luster, and is usually soft and friable, with a "charcoal-like" appearance.

Lateral continuity of lithotype bands within the Sub-3 seam, particularly of clarain and durain bands, indicates the usefulness of megascopic coal seam descriptions in area coal mines. It is likely that other coal seams in the area may also have individual signatures. This may be useful not only for coal seam correlation, but also for future environmental interpretations. It is possible that coal miners could use particular bands for marker horizons when attempting to maintain a particular mining position in a thick coal seam. Further study of lithotype banding could prove to be a valuable tool for geologic interpretations and for mine development.

Microlithotype Analysis

After megascopic field description of the Sub-3 seam was completed, microscopic analysis of observed lithotype bands was initiated with the use of petrographic equipment at the Utah Geological and Mineral Survey. The purpose of this brief petrographic study is to determine the general microlithotype content of each laterally continuous lithotype band within the coal seam in order to further characterize and define each band.

To accomplish this microlithotype study, two full coal seam columns were taken from different localities within the No. 3 Mine.. Column locations are shown in fig. 15. These columns were then cut and polished in their entirety, in order to provide two full polished sections of the Sub-3 seam. The polished columns were then described megascopically and compared with the megascopic field description to ensure that there was no descrepancy between the two. Each lithotype band in each column was then studied petrographically from top to bottom, and percentages of microlithotype groups within each band were calculated. Figure 16 shows the results of this analysis.

As described by Stack (1975), the microlithotype concept is a concept whereby coal macerals within a column of coal are grouped microscopically into stratigraphic bands or units. Three major microlithotype groups,monomaceral, bimaceral, and trimaceral microlithotypes occur, depending on the number of principal maceral constituents. Monomaceral microlithotypes contain one principal maceral constituent, whereas bimaceral microlithotypes contain two and trimaceral contain three. Table 3 gives the classification of the microlithotypes within these three groups, as well as the maceral groups they contain.

During the microlithotype analysis, as outlined by Stack (1975), two conventions, developed by the I.C.C.P., were followed. First, only those bands 50 microns or more thick were recorded as individual microlithotype groups. Second, the so-called "5 percent rule" was followed, which states that a monomaceral or bimaceral microlithotype may contain up to 5 percent accessory macerals which are, by definition, not typical of the particular microlithotype. Because this is a brief study designed to show the general relationships between microlithotypes and lithotype bands, microlithotype identification was only taken to the "group" level.

As can be seen in fig. 16, clarain lithotype bands contain high percentages of both vitrite and clarite, with only minor amounts of other microlithotype groups. In comparing the two polished columns, it was found that percentages of microlithotype groups vary laterally within correlative clarain bands. To determine the reason for, and the exact nature of, microlithotype variation with individual lithotype bands, many more columns of the Sub-3 seam would have to be studied.

Durain bands within the coal seam generally contain lesser amounts of vitrite and clarite, with significant amounts of trimacerite, durite, and carbominerite. Minor percentages of liptite, inertite, and vitrinertite are also common. Again, as with the clarain bands, percentages of microlithotype groups vary laterally within individual durain bands.

In certain cases, particularly in the lowermost durain band in each column (Fig. 16), the microlithotype analysis shows high percentages of clarite. It is possible that this lower durain lithotype band is actually a dull clarain rather than a true durain. Cameron (1978) differentiates clarain into bright clarain and dull clarain in bituminous coals of southern Illinois, and it appears that this concept may be useful for Utah coal beds as well.

In an attempt to determine a microscopic coal seam signature using the microlithotype concept, a vitrite graph was constructed for each coal column for comparison (Fig. 17). The graph simply shows the relative amounts of vitrite in each lithotype band. Because column 1 is not a complete section of the coal bed, due to the fact that a thick siltstone split forms the mine roof at the column 1 location. Therefore, column 1 does not represent as complete a section as column 2. Similaritites still exist, however, between column 1 and the lower portion of column 2. It should be noted that all of the durain bands present in column 1 are present in column 2, at approximately the same position in the coal seam, and that the basal durain band is thicker and contains a thin mudstone split in column 2. This again shows the relationship between durain bands and rock interbeds.

This occurrence of mudstone in a durain band illustrates the importance of lithotype and microlithotype banding studies. Many durain bands, as mentioned previously, potentially grade into rock interbeds at some point within a coal seam. Many localized interbeds or splits, which are not detected by surface drilling, can result in serious coal quality dilution problems. As mining advances in a particular coal seam, however, durain bands could be monitored megascopically and microscopically to observe any increases in mineral matter. This could feasibly aid in the prediction of splits in advance of mining, especially when coupled with surface drill hole information.

MICROSCOPIC CHARACTERISTICS

Maceral Analysis

In order to understand the general maceral content of the Sub-3 seam, a brief maceral and vitrinite reflectance analysis was conducted on polished coal pellets of the seam. The pellets were produced from channel samples taken adjacent to the two coal columns used for the microlithotype analysis. As with the microlithotype analysis, polished coal pellets were prepared and analyzed at the Utah Geological and Mineral Survey.

Vitrinite reflectance and maceral analyses were conducted according to A.S.T.M. Standards (1978). Utilizing this procedure, coal macerals were separated into the following subdivisions: vitrinite, exinite, resinite, micrinite, macrinite, semifusinite, and fusinite. Table 4 shows the results of the maceral inventory and vitrinite reflectance analysis of the two channel samples.

Table 4. Maceral inventory and vitrinite reflectance of two channel samples

	Sample 1 (%)	Sample 2 (%)
Vitrinite	88.9	86.1
Exinite	4.1	3.6
Resinite	1.7	2.1
Micrinite	0.1	0.4
Macrinite	0.0	0.0
Semifusinite	1.9	3.5
Fusinite	3.3	4.3
Max. Mean Reflectance	0.68	0.71

Vitrinite reflectance of the Sub-3 seam indicates a high volative B bituminous rank, which is typical of many east/central Utah coals.

Chemical Analysis

Chemical analyses were run on the same channel samples that were used for the maceral analysis. The analyses were run in order to further characterize the Sub-3 seam. Both proximate and ultimate analyses were conducted, and are tabulated in table 5.

It should be noted that the difference in percent ash in the two samples (12.16 a.r. in sample 1, versus 9.33 a.r. in sample 2) is largely due to the fact that channel sample 1 consists of coal from essentially the lower two thirds of the Sub-3 seam, whereas sample 2 includes the entire coal seam. The ratio of coal to a thin mudstone split which occurred in the lower portions of both samples is much lower in sample 1 than in sample 2. The difference in BTU/lb can also be attributed to the same relationship.

In comparing the chemical analysis with the maceral analysis, it is interesting to note that the slight difference in rank between sample 1 (12242 a.r. BTU) and sample 2 (12997 a.r. BTU) is also mainfested in a lower vitrinite reflectance in sample 1 (0.68) than in sample 2 (0.71).

Table 5. Proximate and Ultimate analyses of two channel samples.

		Proximate Analysis					
		% Mois.	% Ash	% Vol.	% Fix. Carb.	BTU	% Sulf.
Sample 1	AR	2.48	12.16	40.90	44.46	12242	0.75
	DB		12.47	41.94	45.59	12553	0.77
	MAF					14341	
Sample 2	AR	2.03	9.33	41.57	47.07	12997	0.47
	DB		9.52	42.43	48.05	13266	0.48
	MAF					14562	

		Ultimate Analysis							
		%M.	%C	%H	%N	%Chl.	%S	%A.	%O
Sample 1	AR	2.48	68.34	5.08	1.30	0.00	0.75	12.16	9.89
	DB		70.08	5.21	1.33	0.00	0.77	12.47	10.14
Sample 2	AR	2.03	71.97	5.44	1.50	0.00	0.47	9.33	9.26
	DB		73.46	5.55	1.53	0.00	0.48	9.52	9.46

Cleat

Cleat is a common feature which occures in most bituminous coal beds. It can be defined as a natural joint system that occurs exclusively within coal seams, often independent of regional joint or fracture systems which occur in the surrounding strata (McCullock, and others, 1974). Cleat orientation and spacing does have some affect on mining. The frequency of cleat planes may determine the size consistency of the mined coal. The cleat orientation, relative to the direction of mining, may determine how easily the coal can be cut by mining machines (if mining is conducted parallel to the cleat, extraction is usually easier). Cleat orientation relative to mine entry orientation can also have some effect on rib stability on coal pillars. The cleat system may also act as a natural passageway along which coal bed gasses can bleed into mine entries.

The principal or best-developed cleat orientation within a coal seam is termed "face" cleat. The secondary cleat orientation, termed "butt" cleat, is commonly oriented at about a 90-degree angle to the face cleat. Both face and butt cleat are generally well developed in the coal seams of the Book Cliffs and Wasatch Plateau. The cleat system of the Sub-3 seam is readily observable, and measurement of cleat orientation within the No. 3 Mine during mapping and section measuring was relatively simple.

Cleat orientation was measured with a Brunton compass at every measured section location within the mine. A total of 106 measurements of face and butt cleat were obtained and tabulated. Figure 18 shows a rose diagram of the measured face and butt cleat orientations. The average face cleat is N50W, and the average butt cleat is N40E. Individual cleat planes are nearly vertical, with cleat spacing ranging from 1 or 2 cm in vitrain and clarain bands, to 5 or 6 cm in durain bands.

The origin of cleat in bituminous coal seams is uncertain. McCulloch, et at. (1974) mention that three main theories of cleat formation have been proposed. These include both a tectonic and nontectonic theory, as well as a theory incorporating both tectonic and nontectonic processes. The tectonic theory attributes cleat formation to tectonic forces such as those which formed the folded Appalachian coal beds. McCulloch, and others, (1974) found, for example, that the face cleat exposed in many coal mines was nearly perpendicular to fold axes of local anticlines or synclines. The nontectonic theory attributes cleat formation to compaction and dehydration of the coal seam during the coalification process (Moore, 1932). Cleat may also form due to a combination of tectonic and nontectonic processes, a theory which is discussed in detail by Moore (1932).

The average cleat orientation in the Sub-3 seam appears to have no obvious correlation to local geologic structure, which includes several gentle, north--south trending anticlinal and synclinal structures to the east of the minesite. It is possible, however, that the cleat orientation may correspond to the regional structure of the San Rafael Swell, a large anticlinal structure located southeast of the No. 3 Mine. The mine is located in the northwest dipping strata along the flank of the anticline. If this is the case, the N50W trending face cleat is oriented nearly perpendicular to the northeast striking limb of the anticline in the mine area. Much more study of cleat in the surrounding Book Cliffs and Wasatch Plateau coal beds is needed before any relationship between cleat in east-central Utah coals and geologic structure can be ascertained. Regional jointing studies would also be helpful, in comparison to cleat orientation.

Regardless of the origin of the cleat system in the Sub-3 seam, it does have some effect on mining conditions. Because the face cleat is oriented in a northwest/southeast direction, the northeast and southwest corners of coal pillars tend to slab and deteriorate much more readily than the other two corners. This could be an important consideration for pillar failure criteria in sections of the mine where pillars are being extracted. The cleat system also appears to act as a conduit for the transport of methane gas into mine entries, as discussed below. This could be an important consideration for mine ventilation techniques and mine entry orientation.

MISCELLANEOUS GEOLOGIC FEATURES

Associated with the stratigraphy, depositional environments of the immediate mine roof, and general Sub-3 seam characteristics, are a number of miscellaneous geologic features which affect mine roof conditions or coal seam charactertistics to some degree. These features include clastic dikes or "spar," rock splits or partings, coal seam rolls, coal bed methane, and oil seeps. In a geologic sense, some of these features are better understood than others, but since they do affect roof and coal conditions within the Hardscrabble No. 3 Mine, they warrant documentation and brief discussion.

CLASTIC DIKES OR "SPAR"

"Spar" is a local miners' term used to describe sinuous, moderately to steeply dipping clastic dikes which occur in area coal beds. Spar occur in many of the coal seams of the Book Cliffs and Wasatch Plateau Coal Fields, with one of the best known and documented cases occurring in the Trail Mountain Mine, about 60 km south of the No. 3 Mine. Doelling (1977) found that spar in the Trail Mountain Mine (Hiawatha seam) were largely composed of well--indurated, fine-grained sandstone, containing a high percentage of quartz grains cemented by calcium carbonate. Their thickness may range from a feather edge to more than 1 m, and they commonly extend for great lateral distances within the mine, cutting across several entries or crosscuts.

Spar observed in the No. 3 Mine have similar characteristics to those described by Doelling (1977). Generally, the spar occur as linear features which trend from northwest to southeast, and occasionally from west to east. The spar usually extend in a sinuous pattern from roof to floor, and are vertically and horizontally discontinuous. Figure 19 contains several sketches of spar observed in the No. 3 Mine.

Because the Sub-3 seam overlies the massive Spring Canyon Sandstone, it was difficult to determine whether the spar originated from the floor or from sandstone deposits in the roof. In an attempt to determine this, samples were obtained from the marine sandstone in the floor, from the spar within the coal seam, and from fluvial sandstone in the immediate mine roof above the spar. From these samples, thin sections were prepared and studied. Figure 20 compares the grain size distribution of the marine sandstone, spar, and overlying fluvial sandstone. It is readily apparent that the grain size distribution of the spar sandstone is quite similar to the fluvial channel sandstone, indicating that the spar had its source in the sands deposited above the coal bed.

The cause of the injection of the sand into the underlying peat deposit is uncertain. Doelling (1977) proposes a "dessication" model for spar formation in the Trail Mountain Mine. In this model, the peat and its overlying blanket of sand and mud are first deposited. As more and more sediment is deposited, slight synclinal folding occurs and, at the same time, the peat begins to dry and dessication cracks form. Unconsolidated sand from above then fills the cracks. Through time, the peat is coalified and volume loss occurs, and sand in the dessication cracks begins to fold sigmoidally. Sand from the spar is also injection horizontally into horizontal fractures opened at the margins of the spar.

Another model, more related to tectonic events at the time of deposition, is suggested by spar occurrences in coal seams of the Scofield, Utah area, about ________ km southwest of the No. 3 Mine. Occurrences of spar observed and mapped by the author in Scofield area coal mines show orientations which parallel known regional fault trends. It is also not uncommon for spar to vertically parallel joint planes within the coal beds and the overlying rocks. This suggests that the same tectonic forces which created the faults and joints well after coalification of the peat and lithification of the surrounding strata, may have been active even at the time of deposition. If this is true, the spar could have been injected due to liquefaction of the sand during earthquake or some other type of tectonic activity. For this model to work, fractures would also have had to form in the peat during such a tecotnic event. It is uncertain, of course, whether such fractures can or do occur in peat deposits during tectonic events such as an earthquake.

Whatever the origin of the spar, they do appear to have originated from fluvial sand immediately overlying the peat, and they do occasionally cause problems to mining, particularly when their thickness exceeds about 25 cm. When this occurs, coal cutting machines such as continuous miners or longwall shears are hampered by excessive bit wear. In certain cases, if the spar are thick enough, more conventional methods of drilling and blasting have to be used, causing temporary production delays.

At the present time, prediction of spar occurrences in advance of minimg is not possible. More regional studies of spar must be conducted in area coal mines in order to better understand their various occurrences, modes of emplacement, relationship to various depositional settings, and overall predictability in advance of mining.

SPLITS

The term "split" is a mining term used to describe rock interbeds or partings that occur within coal seams. Splits are quite common occurrences in area coal beds, and if not previously encountered by exploratory drilling, may cause unexpected difficulties with coal cutting machinery, as well as dilution of overall coal quality.

Only one split of significant thickness has thus far been encountered during mining in the No. 3 Mine. The No. 3 Mine portals were driven beneath this split during initial mining. At the mine portal, the mined portion of the Sub-3 seam is 1.6 m thick, and is overlain by 1.5 m of siltstone. This siltstone layer is in turn overlain by another 21 cm of coal, representing the upper part of the Sub-3 seam. As initial mining advanced in a northerly direction (Fig. 3), the upper and lower portions of the Sub-3 seam eventually merged, signficantly increasing the thickness of the minable coal seam.

The pinchout line of the siltstone split has a northeast-southwest trend, indicating that the source area for the siltstone may have been to the southeast. The split could be the result of overbank splay deposition from a nearby fluvial system that flooded a portion of the coal swamp. The siltstone that resulted is generally massive, hard, and shows only faint bedding characteristics. No fossils or burrowing are apparent, and there is a surprising lack of carbonaceous material. This may indicate that deposition of the silt may have been quite rapid, possibly only one or two short-lived depositional events. Immediately after the silt was deposited, the swamp apparently re-established itself on the platform of silt now represented by the siltstone split.

Other minor splits occur in the Sub-3 seam which, for the most part, have had little, if any, effect on mining or coal quality. One of these splits occurs throughout the entire No. 3 Mine, making the Sub-3 seam within the mine area rather easy to recognize. This split is about 8 to 12 cm thick throughout the mine, and is composed of silty mudstone. Stratigraphically, within the coal seam, it is located from 1 to 1.2 m above the sandstone floor rock. Figure 13 shows the laterally continuous nature of this split, as well as the locations of several other laterally discontinuous splits in the coal bed.

COAL SEAM ROLLS

As mentioned previously, the term "roll" is a local miners' term which is applied to large scale undulations of an entire coal seam, including both roof and floor rock. Figure 5 is an illustration showing a typical roll in the No. 3 Mine.

Many coal seam rolls, not only in area coal mines, but in numerous mines throughout the U.S., are the obvious result of differential compaction beneath large channel sandstone lenses (McCabe and Pascoe, 1978, and Mercier and Lloyd, 1981). Because the Sub-3 seam immediately overlies a massive marine sandstone, however, it is questionable whether the rolls within the seam are related to channel sandstone bodies, or rather to topographic undulations of the underlying beach sandstone. Differential compaction of a thick beach sandstone sequence beneath a paleochannel would seem highly unlikely. If, on the other hand, the coal seam were deposited and compacted over an already undulating marine sand surface, coal seam rolls could occur without the presence of channel sandstones, which is the case for many rolls in the No. 3 Mine.

Much more study of coal seam rolls is needed to ascertain their origins and predictability, particularly for rolls that occur in coal beds which overlie massive marine sandstones as does the Sub-3 seam. If the rolls reflect the topography of the marine sandstone, they may indicate the presence of tidal channel scour zones or beach ridges along the paleoshoreline. Because channel-fill sandstone bodies do occur directly above many of the rolls (as shown in Figure 5), it may be possible that distributary or spaly channels actually followed the topographic lows in the marine sand, even after peat deposition.

During mine mapping activities, the author made an attempt to determine if the coal seam thickened or thinned withn the roll area. If the roll were the result of a paleotopographic low, the coal which formed in the low should be slightly thicker than nornal. A series of thickness measurements were measured in 3 m intervals across two major rolls in the No. 3 Mine. The measurements indicated virtually no variation in seam thickness. This lack of change gives rise to further questions about the origin of the rolls. Much more must be known before attempts can be made to predict the occurrence of rolls in advance of mining.

Coal seam rolls do affect mining conditions in several ways. The steep, irregular inclines of many rolls make it difficult for mining machinery such as continuous miners, longwall machines, and haulage machines to operate efficiently. Also, after mining, they often become areas where mine water collects and must be constantly pumped. A more complete understanding of the nature and origin of coal seam rolls may result in successful predict of their their occurrence and size prior to mining.

METHANE

The presence of methane gas within the coal beds in certain parts of the Book Cliffs and Wasatch Plateau Coal Fields has been well documented by Doelling, and others, (1981). The gas, which is a natural byproduct of the coalification process, occurs within specific "gassy" areas, one of which includes the coal seams of the No. 3 Mine area. In the Hardscarbble No. 3 Mine, as in any mine where methane is present, special safety precautions to detect and eliminate the gas during mining are of great importance.

During mapping of the No. 3 Mine, the author encountered numerous locations where gas was forming bubbles in pools of water on the mine floor. These locations provided excellent places for sampling the gas. A total of four gas samples were obtained, utilizing specially designed vacuum bottles provided by the U. S. Bureau of Mines. The gas was collected by completely filling the bottle with water and then holding it upside down over the location where bubbles were being emitted from the bottom of the pool. As soon as the water in each of the bottles was completely displaced by gas, the bottles were sealed. Table 6 shows the results of gas chromatography analysis of the collected samples.

Table 6. Gas chromatography analysis of collected methane samples

Sample	Major Component (percent)										Trace Comp.(
No.	CO_2	O_2	N_2	CH_4	C_2H_6	C_3H_8	$I-C_4H_{10}$	$N-C_4H_{10}$	$I-C_5H_{12}$	$N-C_5H_{12}$	
1	0.8	1.3	5.1	92.8	0.49	0.09	0.03	0.04	0.04	0.03	0
2	.16	1.32	5.52	91.3	1.03	0.36	0.09	0.09	0.06	0.03	0
3	.13	1.33	5.35	91.55	1.03	0.33	0.09	0.09	0.06	0.04	0
4	.58	1.45	6.17	91.57	0.18	0.04	44 ppm	66 ppm	15 ppm	14 ppm	139 ppm

Sample	BTU/Ft3 *		Spec.
No.	Gross	Net	Grav.
1	955.0	860.0	0.59
2	961.0	866.0	0.60
3	963.0	866.0	0.60
4	931.0	838.0	0.59

*at 760 MM HG & 60 deg. F.

One of the interesting characteristics of the collected gas is the nearly atmospheric proportions of oxygen and nitrogen. The nitrogen/oxygen ratio of samples 1 through 4 are 3.9, 4.2, 4.0, and 4.3 respectively. This compares to a 3.7 atmospheric nitrogen/oxygen ratio. The reason for this similarity is uncertain. It is, of course, possible that the samples were contaminated during sampling or analysis. However, this is unlikely due to the fact that the sample bottles were filled and sealed underwater, and analyzed in a controlled laboratory environment. Another possibility is that atmospheric gases migrated from mine entries along the cleat system in the coal bed and mixed with methane, which also migrates in the cleat system. The gases would mix as they reach equilibrium within the mine environment. If this is the case, it shows that the cleat system does form a migration path for mine gases.

Because sampling of the gas was conducted from the sandstone floor of the mine, it is also obvious that coal bed gas migrates from the coal seam into the underlying marine sandstone, and then back out into mine entries. Some mixing of atmospheric gases and mine gases could also occur in the permeable sandstone.

OIL SEEPS

One of the most peculiar geologic phenomena observed within the Hardscrabble No. 3 Mine was the occurrence of an oil seep in the western part of the mine. The seep consists of oil that drips from the base of a channel-fill sandstone body, forming large pools of oil on the floor of the mine. Figure 21 shows the relationship of the oil to the paleochannel body.

The oil appears to be of relatively good quality. It is quite fluid and drips readily from the base of the channel sandstone. During mapping of an overlapping coal mine in the Castlegate D seam, I also observed a similar oil seep dripping from a channel sandstone body. Other occurrences are also known in the Royal Mine (now abandoned), just northeast of the No. 3 Mine.

The oil has apparently migrated into the paleochannel bodies in localized areas, and when encountered, has been a nuisance to the coal miners who must work beneath it. Its odor can be quite annoying within the confines of the mine entries, and for short periods of time it has been known to pour quite profusely from roof bolt holes. If the pools of oil that collect on the floor beneath the seeps are not pumped and removed from the mine, a fire hazard also exists. However, because these oil occurrences are so rare they are not a major concern for the mining company.

CONCLUSION

Underground mapping in the Hardscrabble Canyon No. 3 Mine has shown that the geology of the immediate mine roof has had a profound effect on roof conditions of the mine. A majority of the roof instability in the No. 3 Mine is related to paleochannel sandstone lenses and their associated overbank deposits of thin-bedded sandstone. By mapping these deposits in the mine roof, and projecting them into unmined areas with the aid of surface drill hole data, areas of geology-related roof stability problems can be predicted in advance of mining. In general, four roof fall types have been classified in the No. 3 Mine. These include: 1) falls associated with channel-fill sandstone bodies, 2) falls associated with overbank sandstone deposits, 3) falls associated with fracturing of overbank siltstone deposits, and 4) "cathedral" falls which appear to be unrelated to roof geology. Because three of these roof fall types are associated with specific depositional facies, depositional studies within the No. 3 Mine should continue as mining proceeds.

Coal seam characteristics of the Sub-3 seam are quite typical of many bituminous coal beds in the mine area. Measured sections within the mine show that lithotype banding within the seam is laterally persistent, and that mapping of lithotype bands may eventually prove useful for future coal seam correlation work, as well as for maintaining mining positions in thicker coal seams. Microlithotype studies may also be helpful for correlating lithotype bands, as well as eventually determining their environments of deposition.

Numerous other features also affect mining conditions in the No. 3 Mine. These geologic features include such things as clastic dikes or "spar," rock parings or splits, coal seam rolls, coal bed gas, and oil seeps. Because many of these features are poorly understood, a more regional study of their occurrences in other coal mines of the Book Cliffs and Wasatch Plateau will be helpful for determination of their origins, as well as for their prediction in advance of mining.

Underground geologic mapping and analysis are important, not only in understanding of roof and coal seam conditions within underground coal mines, but in predicting of geologic conditions in advance of mining. By careful monitoring and mapping roof strata as mining advances, the relationship between depositional environments and roof conditions can be evaluated. This information is vital to mine safety and production. Existing drill hole information can also be used to project expected roof conditions into proposed mine areas. Detailed study of coal seam characteristics can help in the prediction of coal quality as well as aid in the mining process.

APPENDIX B.

GEOLOGY OF THE DEADMAN CANYON 7 1/2 MINUTE QUADRANGLE,

CARBON COUNTY, UTAH

A thesis submitted to the Department of Geology

in partial fulfillment of the degree Master of Science

Submitted by:

Mark A. Nethercott

April 8, 1983

ABSTRACT

The Deadman Canyon 7 1/2 Minute Quadrangle is a major coal producing area and contains rocks ranging in age from the Late Cretaceous Mancos Shale to the Early Eocene Flagstaff Formation. The coal-bearing upper Cretaceous Blackhawk Formation was subdivided for mapping into the Spring Canyon, Aberdeen, Kenilworth, lower mudstone, Sunnyside, and upper mudstone members. Price River and North Horn formations were each subdivided into lower and upper unnamed members. The contact between the fluvial Price River Formation and fluvial-lacustrine North Horn Formation, as described by previous workers, is difficult to map with confidence. Therefore, the contact was mapped at the top of a prominent sandstone that crops out continuously as a cliff across the quadrangle. Littoral sandstones of the Blackhawk Formation represent prograding wave-dominated deltas that interfinger eastward with tongues of marine Mancos Shale. Coal-bearing rocks were deposited in associated Cretaceous paralic, delta plains, and coastal plain swamps that roughly paralleled the strandline. The Gilson, Castlegate "A", Lower Sunnyside, and possibly the Castlegate "B" coal zones reach average coal thicknesses that permit economical subsurface mining operations. Thickness averages for the main coal zones are as follows: Gilson seam 1.5 m (4.9 ft), Castlegate "A" seam 1.1m (3.3 ft), Castlegate "B" seam 0.8 m (2.5 ft), and Lower Sunnyside coal 1.1 m (3.6 ft). The above averages cover measurements for the entire quadrangle except for the Castlegate "A" and "B" coals that are restricted to the western half of the quadrangle. The Kenilworth (0.7 m = 2.0 ft) and Rock Canyon (0.9 m = 2.8 ft) coal zones show possible potential for future in situ coal gasification and subsurface mining, as future economic conditions permit. More data from exploratory wells are needed to more accurately estimate development potential of these thinner coal zones

in the quadrangle.

INTRODUCTION

The Deadman Canyon 7 1/2 Minute Quadrangle is situated in the Book Cliffs Coal Field, approximately 16 km (10 miles) northeast of Price, Utah. Development of the Cretaceous coals in the Quadrangle is of prime concern. Understanding of the stratigraphy of both coaland noncoal-bearing rocks, structural geology, and depositional environments will aid in determining coal exploitation potential of the quadrangle. Early regional studies of the area were focused on stratigraphy and structural geology of the Wasatch Plateau and Book Cliffs. Clark (1928) mapped the geology and made a reconnaissance coal survey from Helper to Sunnyside, Utah. Others have concentrated their studies on the stratigraphy and depositional environments of the coal-bearing rocks in the Book Cliffs as a whole. A geologic map (Nethercott, 1983, in press) was constructed on a scale of 1:24,000 and published by the Utah Geological and Mineral Survey. Five important coal zones (horizons) in the Blackhawk Formation were mapped and measured, both at the outcrop and in the subsurface. Coal isopach and rock interburden maps help estimate coal development potential. Data from coal and petroleum exploratory wells drilled in the quadrangle, combined with outcrop information, were used to construct a structure contour map of the area. Other data collected from measured stratigraphic sections were used to interpret depositional environments of the rocks in the quadrangle.

LOCATION AND ACCESSIBILITY

The Deadman Canyon 7 1/2 Minute Quadrangle is located in the Book Cliffs of Carbon County, Utah (Fig.1). The area is bordered by the Helper Quadrangle to the west, the Minnie Maude West Quadrangle to the north, the Pine Canyon Quadrangle to the east, and the Wellington Quadrangle to the south. Access into the area is good. Two partially paved roads to coal mines and Utah State Highway 53 provide the main access. Numerous unimproved jeep roads also cross the area. Most of the land in the Book Cliffs and in Emma and Whitmore Parks north of the Book Cliffs is privately owned. Permission from the owners is required to enter some of the land.

PREVIOUS WORKS

Most previous work in this area has focused on the economic potential of the coal-bearing rocks. Taff (1905) studied the coal field between Sunnyside and Castlegate, mapping only the top and base of the coal-bearing units. Clark (1982), made a detailed study of the geology and economic geology of the Castlegate, Wellington, and Sunnyside Quadrangles in Carbon County, Utah. He described the stratigraphy and general structural geology, and published maps of part of each quadrangle from Castlegate to Sunnyside, including Deadman Canyon, on a scale of 1:42,240. Young (1955,1957, 1966, 1976,) studied the rocks of the Western Book Cliffs, emphasizing stratigraphy and depostional environments of the Blackhawk Formation. Anderson (1978), mapped and studied the geology and coal resources of the area directly east of the Deadman Canyon Quadrangle. Balsley (1982) studied the stratigraphy and interpreted the paleoenvironments of the coal-bearing rocks of the Book Cliffs of central Utah. Others, such as Osterwald, et al., (1981), Parker (1976), Doelling and Graham

(1972), studied the economic potential and paleoenvironments of the coal units in the area. Rich (1935) discussed the origin and evolution of rock fans in and around the Deadman Canyon Quadrangle. Spieker (1946,1949) described the geologic history of central and eastern Utah. Fisher, et al.,(1960) studied the Cretaceous and Tertiary formations in Carbon County. Van de Graff (1972) described the fluvial facies of the Castlegate Sandstone.

METHODS

Fieldwork was done between late May and late September 1982. Stratigraphic sections were measured with a Jacob's Staff. A 12-foot metal tape was used to measure coal sections. Geology and coal outcrops were mapped on aerial photos at a scale of 1:31,000. Data were then transferred to the Deadman Canyon 7 1/2 Minute Quadrangle topographic sheet. Channel samples of main coal seams were collected at various locations throughout the area. Each sample was collected in a plastic bag and sealed with tape. These samples will be analyzed by the Utah Geological and Mineral Survey as part of a subsequent study by their personnel.

ACKNOWLEDGMENTS

J. K. Rigby served as thesis chairman and H. J. Bissell and J. L. Baer served as committee members. Financial assistance was received from the Utah Geological and Mineral Survey under Department of Energy Grant DE-FG21-80MC14257. Michael Glassen and Tower Resources aided me in my subsurface work. Robert Nethercott, Darin Singleton, and Michael Child assisted in field work. Special appreciation goes to my wife, Christie, for her help and support.

STRATIGRAPHY AND SEDIMENTATION

General Statement

Exposed rocks in the Deadman Canyon Quadrangle range in age from Late Cretaceous to Early Tertiary (Fig.2). The oldest exposed formation is the Mancos Shale, which is overlain by the upper Cretaceous Mesaverde Group. Only a partial section of Mancos Shale is found in the area. Star Point Sandstone, Blackhawk Formation, Castlegate Sandstone, and Price River Formation constitute the Mesaverde Group. The younger North Horn Formation is time transgressive and straddles the Late Cretaceous and Early Tertiary boundary. Flagstaff Limestone is of Paleocene-Eocene age, and is the youngest Tertiary formation preserved in the area. Quaternary deposits consist of stream alluvium, slope wash, colluvium, and pediment gravels. A possible unconformity is present between the Blackhawk Formation and Castlegate Sandstone in the Deadman Canyon Quadrangle. A major unconformity is found between Cretaceous and Tertiary rocks and Quaternary surficial gravel deposits. Maximum thickness of rocks studied in the area is approximately 1760 meters. The section from the top of the Mancos Shale to the top of the Flagstaff Limestone thins from west to east, with most thinning occurring in the Blackhawk Formation. The section as a whole is composed predominantly of clastic rocks including shale, mudstone, sandstone, and siltstone. Major coal seams are found in the Blackhawk Formation. The North Horn Formation and Flagstaff Limestone contain thin freshwater limestones. Contacts between the North Horn and Price River Formations were difficult to map. Identification of a mappable North Horn-Flagstaff Formationcontact was also difficult. Subdivision of the Blackhawk Formation into members varies from author to author. Nomenclature depended chiefly upon the author's goals and upon the geographic location of his study.

Cretaceous System

Mancos Shale

Upper beds of Mancos Shale crop out in the lower or southern half of the Deadman Canyon Quadrangle (Fig.3), and are covered with pediment gravels and slope wash. The shale is exposed in steep slopes underneath ledges of protective gravel or resistant sandstones, Badland topography is developed in some of these steep slopes. Where not protected by overlying resistant units, the Mancos Shale forms gentle slopes or open valleys (Fig.4). Generally, the soil formed by weathering of the Mancos Shale is impermeable; therefore most precipitation runs off. For this reason deep ravines or washes cut through the broad valleys formed in the shale. In these washes fresh outcrops of Mancos Shale are exposed. Such exposures have a nodular or botryoidal appearance, typical of massive mudstone or claystone. Calcareous shale, silty shale, siltstone, sandstone and minor lentils of limestone (Young, 1955, p. 182) are dominant rocks in the Mancos. Fresh colors range from medium gray to bluish gray, whereas weathered slopes exhibit blue or brownish gray colors. Localized lentils of siltstone and sandstone, from a few mm to several cm thick, occur throughout the section. More resistant sandstone beds hold up minor cuestas or cap knolls of shale. Sandstones range from medium gray brown on a fresh surface to pale yellowish orange on weathered surfaces, are very fine-grained, and occur in beds usually less than one meter thick. Locally these lentils contain high amounts of carbonaceous material. Fragments of wood, up to 8 cm long, occur in some beds. Sandstone beds tend to be fossiliferous. An echinoderm, ammonoid fragments, and several bivalves were observed. The sandstones are commonly bioturbated; burrows attain diameters of 0.8 cm. Sandy calcareous concretions that contain cephalopods, bivalves, or other organic fragments also occur in the sandstone and siltstone (Osterwald, et al., 1981, p. 15). Total thickness of the Mancos Shale in the Book Cliffs area of Carbon County ranges from 1,432 meters to 1,539 meters (Clark, 1928).

In western Colorado the Mancos is about 1,230 meters thick. Exposed thickness of Mancos Shale measured at Coal Creek totals nearly 750 meters. The shale intertongues with the Star Point Sandstone and lower Blackhawk Formation. Mancos Shale tongues thin toward the west and the sandstone tongues thin toward the east. Lower contacts of sandstone tongues are gradational, whereas upper contacts are sharp. Such interfingering results in a stratigraphic rise of the upper boundary of the Mancos from west to east. The upper boundary, therefore, becomes progressively younger toward the east (Young, 1955, p. 182). Rocks near the boundary between Mancos and Blackhawk formations are assigned an early Campanian age in the western Book Cliffs region (Young, 1966, p. 11). Mancos Shale is believed to have been deposited in a shallow marine environment (Howard, 1966; Maxfield, 1976). Young (1955), stated that sediments of the Mancos Shale accumulated in a marine environment past the mud--sand transition line. However, most of the mud was probably deposited near shore. Lithology and trace fossils, combined with other paleontological evidences, support Howard's and Young's conclusions.

Star Point Sandstone

Three sandstone tongues were originally assigned to the Star Point Sandstone. In ascending order they are the Panther tongue, Storrs tongue, and Spring Canyon tongue. Young (1955, p. 182) redefined the Star Point as consisting of the basal Panther tongue and overlying Storrs tongue. The Spring Canyon tongue was assigned to the Blackhawk Formation. The Star Point Sandstone occurs in the northern Wasatch Plateau and western Book Cliffs of central Utah. This formation interfingers with the Mancos Shale, and pinches out to a feather edge northeast of Wellington, Utah. The Storrs tongue is not recognizable in the Deadman Canyon Quadrangle for it pinches out about 2 km east of Kenilworth, Utah. Younger Panther sandstone, however, is more persistant and is mappable in the Deadman Canyon area. It thins across the quadrangle, but does not pinch out untilit reaches Fish Creek, several kilometers east of Soldier Creek (Anderson, 1978, p. 17). Maximum thickness of the Panther tongue is 40 m in the Wasatch Plateau, and ranges in thickness from 24 m to 5.5 m in the Deadman Canyon area. Where not covered by colluvium, the Panther beds form a cliff (Fig.5). The Panther tongue can be subdivided into two lithologic units, a basal interbedded siltstone and sandstone and an upper sandstone. Sandstones of the basal unit are very fine-grained, and have a clay and silt matrix that is rich in organic material (Howard, 1966, p. 27) Primary dolomite is also a constituent in the sandstone (Sabins, 1962). Sandstone coarsens upward and becomes finer grained to the east, and bed thickness increases upward in the section. Fresh color of these sandstones ranges from medium gray or gray brown, and weathered surfaces are medium grayish orange. As the amount of silt increases, the weathered color changes to medium gray. Siltstones weather medium gray, and are often heavily bioturbated, which gives the rocks a mottled appearance. Rocks of the lower lithologic unit are thin bedded, ripple marked, and commonly exhibit hummocky bedding. The upper sandstone lithology consists predominantly of fine-grained sandstone. Grains are 90% quartz, with minor amounts of limonite and disseminated organic material. Like the lower unit, these sandstones are mottled due to bioturbation. These rocks are medium to thick-bedded, with horizontal to subhorizontal stratification. At Coal Creek, and farther east, calcareous sandstone concretions are found in the member, usually in the upper sandstones. Concretions increase in numbers as the Panther tongue is traced eastward, they range from a few centimeters to a meter or more in diameter. Body fossils are not common in the Panther tongue. One bivalve (Inoceramus?) was found in the lower 1 m of the tongue at Alkali Creek. Trace fossils are very abundant, however, and most of the identifiable burrows are located in the upper unit. Such trace fossils as Arthrophycus, Ophiomorpha, chevron trails, and annelid worm smooth tubes, (Howard, 1966) are among the most common in the Panther in the quadrangle. Fossils collected by Clark and Spieker have been used to date the Star Point as medial Montanan (Campanian) (Young, 1955, p. 182).

Howard, (1966, p. 32) concluded that sediments of the Panther Sandstone near Helper, Utah were deposited in a delta and associated offshore areas. He considered the basal interbedded siltstone and sandstone to be bottomset beds and the overlying sandstone as forset beds of the delta. Panther sandstone in Deadman Canyon Quadrangle probably represents a transition zone and lower shoreface environment offshore from a delta. The basal interbedded siltstone and sandstone were deposited in a transition zone between the offshore mudstone environment of the Mancos Shale and the lowermost lower shoreface environment of the delta front sheet sands. Rocks of the upper sandstone were deposited in a lower shoreface environment. Sediments deposited in the Cretaceous Panther delta were probably transported offshore as suspended load by turbidites and storms. This is supported by the fact that as the tongue is mapped eastward, away from the Panther delta, grain size of the Panther Sandstone decreases. Harms (1975, p. 89) stated that hummocky stratification, found in Upper Cretaceous rocks of the Western Interior of the United States, represents deposition of sediments under storm wave conditions. Sole marks and hummocky beds suggest the Panther Sandstone sediments were deposited offshore by turbidites and/or storm conditions.

Blackhawk Formation

Young (1955, 1957, 1966, 1976) subdivided the Blackhawk Formation into the Spring Canyon, Aberdeen, Kenilworth, Desert, and Grassy members. Using this nomenclature, each member contains a basal sandstone unit, and associated overlying coal-bearing rocks. Young's nomenclature was modified by Maberry (1971), who subdivided the formation into the Aberdeen, Kenilworth, unnamed lower mudstone, Sunnyside, and unnamed upper mudstone members in the Sunnyside area. The Aberdeen, Kenilworth, and Sunnyside members consist mainly of cliff--forming sandstones. The lower and upper mudstone members are slope forming, and contain mudstone, siltstone, sandstone, and major coal-producing zones. The Spring Canyon Member is not separately recognizable in the area of Maberry's study, but is in Deadman Canyon Quadrangle (Fig.6). Maximum thickness of the formation is approximately 400 meters near Castlegate, Utah. The formation is 327 meters thick at Coal Creek Canyon in this study area, and it continues to thin eastward from there. The Blackhawk Formation consists mainly of sandstone, siltstone, mudstone, shale, and coal. As with the Star Point Sandstone, the lower Blackhawk Formation is a series of sandstone tongues that interfinger with the Mancos Shale (Fig.7). Major sandstones are very fine to medium-grained, and they coarsen upward. Weathered colors are pale yellowish orange to gray orange, and the upper one to two meters of several of the sandstones are light gray. Rocks are thin to thick bedded, and exhibit bedding structures such as hummocky beds, trough crossbeds, and horizontal stratification. Bioturbation is locally intense throughout the sandstones.

The slope areas between sandstone tongues consist of carbonaceous shale, siltstone, mudstone, and coal, along with thin-bedded lenticular sandstone. These rocks are usually medium grayish brown to medium dark brown and are generally covered. Occasional beds of well preserved plant fossils and mollusks occur in the slope intervals. The Blackhawk Formation has been dated by Spieker (1925, p. 444) as medial Montanan (Campanian), based on plant fossils identified by F. H. Knowlton. The contact between the Blackhawk Formation and Castlegate Sandstone is an angular unconformity in the Wasatch Plateau (Clark, 1928, Spieker, 1937, and Young, 1955). The upper contact becomes disconformable west of the Wasatch Plateau front, but as one proceeds eastward the contact becomes conformable (Van de Graff, 1966, Osterwald, et al., 1981). Generally, the precise Blackhawk-Castlegate contact is not widely exposed because the slope-forming upper Blackhawk beds are often buried by Castlegate debris. The contact, where identified, appears to be conformable in the Deadman Canyon Quadrangle. However, an abrupt increase in grain size from the Blackhawk Formation to the Castlegate Sandstone may suggest an unconformity. Prograding deltas and/or barrier island complexes are considered to represent the environments of depostion of the major cliff-forming sandstone members, whereas terrestrial and transitional environments are represented in the mudstone members. The Blackhawk Formation records the final retreat of the Mancos sea from central Utah.

Using a combination of subdivisions, recognized by either Maberry or Young, I mapped six members of the Blackhawk Formation. The lowest one is the Spring Canyon Member, succeeded upward by the Aberdeen, Kenilworth, lower mudstone, Sunnyside, and upper mudstone members (Fig.8). Spring Canyon, Aberdeen, Kenilworth, and Sunnyside Members consist of one or more sandstone tongues or bars. These littoral sandstone tongues can be subdivided into four distinct lithologic units that represent different depositional environments (Fig.9). All four of these lithologic units may or may not be present in the same sandstone at one time. The lowest unit (lithologic Unit I) consists of interbedded siltstones and sandstones (Fig.10). Siltstones weather medium gray, whereas sandstones are pale yellow orange or gray orange. These rocks are generally heavily bioturbated and both siltstone and sandstone display a mottled appearance. The most common trace fossils are Ophiomorpha, Asterosoma, and Helminthoida. Sandstones are very fine-grained, and are composed mostly of quartz, with varying amounts of limonite, lithic fragments, and carbonaceous detritus. Bed thickness ranges from 8 to 30 centimeters, with thickest beds at the top. Hummocky and horizontal stratification occur, along with sharp-- crested wave ripple marks, ripple cross lamination, and scattered sole tool marks (Balsley, 1980, p. 142).

Both upper and lower contacts of the unit are gradational. Rocks of lithologic unit I generally represent transition between lower shoreface and open marine environments (Anderson, 1978, p. 69; Balsley, 1982, p. 42) (Fig.9).

Lithologic unit II weathers yellowish gray and medium grayish orange. The unit consists of very fine-grained quartz sandstone, with limonite, and lithic fragments, in a carbonaceous matrix, and cemented with calcite and minor silica. Beds range in thickness from 30 cm to 2 m, in an overall unit that is 12 to 30 m thick. Hummocky and horizontal (flat) stratifaction are common. Bioturbation is moderate to intense, with some of the dominant trace fossils being Ophiomorpha (both horizontal and vertical), Cylindrichnus, Asterosoma, Teichichnus, Chondrites, Thalassinoides, Gyrochorte, Aulichnites, Terebellina, annelid worm burrows, and helicoidal funnels. These burrows are commonly filled with sediments that have a higher amount of carbonaceous content than surrounding rocks. Lithologic unit II is characteristic of a lower shoreface environment (Fig.9). Sediments in this environment were affected mainly by bioturbation during calm periods, and by storm wave action, represented by hummocky beds.

Lithology III is fine to medium-grained quartz sandstone that contains minor amounts of disseminated carbonaceous material. Grains are mostly quartz with two to five percent lithic fragments (black chert) and feldspar (weathered to kaolin). Weathered color is usually gray orange, but can also be very light gray. Bioturbation is locally intense in the unit; Ophiomorpha, Cylindrichnus, and smooth tube burrows are common trace fossils. Where bioturbation is intense, weathered sandstones can take on a "swiss cheese" appearance, which is, however, not exclusive to the third unit. Lithology III shows dominant trough cross bedding with the sets ranging between 0.2 and 0.5 meters high. Thickness of the unit ranges from 2 to 7 m. Distinguishing features of litholgy III (Fig.9) are characteristic of high energy, upper shoreface, deposits in modern enviornments (Heward, 1981, p. 227), and when found in upper Cretaceous rocks of the western United States have been interpreted as representing an upper shoreface environment (Harms, 1975, p. 89; Anderson 1978, p.76; Balsley, 1982). Study of the upper shoreface sandstones (lithology III) in the Blackhawk Formation, shows that trough cross bed axes orientation are either normal or parallel to the strandline (Balsley 1982, p. 106).

Lithology IV consists of fine-grained sandstone that is mostly quartz (96%), with minor black chert, feldspar, and moderate amounts of carbonaceous

material. Fresh color is medium dark gray, and weathered color is usually light gray. This unit forms a conspicuous "white cap" on several of the major sandstones, although a "white cap" is not characteristic of the upper unit only, for caps may also be seen in the upper few meters of lithology III, in sandstones that do not have this overlying fourth unit. It has been suggested that the "white cap" is present because of a lack of iron-bearing minerals in the sandstone (Young, 1966, p. 13, Anderson, 1978, p. 81). The fourth unit commonly is one to two meters thick, and is characterized by horizontal to subhorizontal stratification that dips seaward at 2-6 degrees (Fig.11). Upper and lower contacts of the unit are sharp. Bioturbation is minimal with only occasional burrows, and minor root casts (Fig. 12).
I found no fossils in rocks of this unit, but Anderson (1978, p. 83) found a bivalve fauna in the Soldier Creek area. The features just described have been interpreted as indicating foreshore or beach environment deposits both in modern and ancient environments (Dickinson et al, 1972, p. 195; Harms, 1975, p. 89; Reading, 1978, p. 147; Balsley, 1982, p. 108).

All four lithologic units are not necessarily present in the same sandstone tongue. Sandstones showing an incomplete sequence usually exhibit lithologies I, II, and sometimes III. Occasionally lithology I will be greatly reduced in thickness and consist of only a meter or two of interbedded siltstone and sandstone (Balsley, 1982, p. 78). Lithologic units II or III can also be seen directly overlying sandstone of lithology IV in some of the stacked regressive sandstones of the Aberdeen Member.

Orientation of a paleostrandline has been determined by Balsley (1982, p. 61) who measured the orientation of trough cross bed axes at over 4,500 localities in five different bars of the Blackhawk Formation. A general strandline orientation of northeast to southwest was calculated using the trough crossbed measurements combined with distributary channel transport direction, gravitational movement of pillow structures, and the fact that flood-plain coals (Gilson seam) tend to pinch out to the southeast.

Spring Canyon Member.

It consists of basal sandstone tongues with overlying coal-bearing rocks in the western Book Cliffs (Young 1955, p. 184), but in the Deadman Canyon area the member is composed of four sandstone tongues separated by tongues of Mancos Shale (Fig.7). The sandstone tongues are all similar in lithology, bedding structures, and trace fossils. Rocks of lithologic units I and II comprise the four tongues of the Spring Canyon Member in the quadrangle. All four sandstone bars thin from west to east, and the Mancos Shale interfingered tongues thin from east to west. The second and fourth sandstone tongues were mapped across the quadrangle, but the first and third tongues lose their identity in the Mancos Shale within the quadrangle (Fig.7). The member is predominantly a cliff-forming fine-grained sandstone that grades laterally to a slope-forming sandy siltstone unit. Local maximum thickness of the Spring Canyon Member is about 46 m near Deadman Canyon and minimum thickness is 40 m near Soldier Creek. The thickest sandstone tongue is 15 m and the thinnest has a maximum thickness of 8 m. Tongues of Mancos Shale occur above and below the Spring Canyon Member. Contacts are gradational at bases of sandstone tongues, and sharp at their tops. Young (1955, p. 184) stated that the upper contact of the Spring Member is slightly disconformable. Coal is not abundant in the Spring Canyon Member of the Deadman Canyon Quadrangle. Minor thin and lenticular coal beds are found in the member immediatly west of Deadman Canyon, however. The Spring Canyon sandstones, like the Panther Sandstone, represent distal margins of wave-dominated shore and near shore deposits in the Deadman Canyon Quadrangle. Sediments associated with the Spring Canyon tongues in Deadman Canyon, were deposited offshore from wave-dominated deltas much like that already described in the Panther Sandstone tongue of the Star Point Sandstone. Sands were carried offshore, away from the delta fronts, by storms, and possibly turbidites. Mudstone and siltstone were deposited during normally calm periods when deposition was generally slow.

Rocks of lithology II are much thicker and much more developed in the Spring Canyon Member than in the Panther tongue. This suggests that the amount of sediments deposited in the Spring Canyon deltas was greater than the amount of sediments deposited in the Star Point deltas, and probably that the Spring Canyon deltas prograded farther east into the Mancos Sea than the Star Point deltas. Shale or siltstone tongues between the sandstone tongues represent offshore shallow marine deposits like the Mancos Shale, and record transgressions of the Mancos Sea over the regressive Spring Canyon delta fronts.

Aberdeen Member

The Aberdeen Member can be mapped across most of the western Book Cliffs from Price River Canyon to Whitmore Canyon (Maberry, 1971, p. 22). It consists of one or more sandstone tongues or bars, which are often separated by tongues of Mancos-like siltstone and shale. According to Young (1955, p. 184) the Aberdeen Member, from Kenilworth to Coal Creek Canyon, is composed of five littoral sandstone bars. Each tongue eventually grades laterally into the Mancos Shale. Six major Aberdeen sandstone bars are found in Deadman Canyon Quadrangle (Fig.7). Sandstones increase from four tongues at Deadman Canyon to six tongues that continue eastward from Coal Creek to Soldier Creek. Sandstone tongues of the Aberdeen Member consist of lithologic units I through IV. Thicknesses of the Aberdeen Member range from 45 m at Deadman Canyon to nearly 75 m at Alkali Creek. Individual sandstones reach a maximum thickness of 30 m, but average about 18 m. The Aberdeen Member is underlain by a tongue of Mancos Shale; the contact between the two is gradational. Contacts were mapped where interbedded siltstone and sandstone become most abundant in the lowermost tongue, which coincides with the base of the lowest sandstone cliff. The upper contact of the Aberdeen Member is sharp and was placed at the top of the uppermost sandstone.

The second sandstone tongue from the base of the Aberdeen Member, east of Straight Canyon, consists of seaward dipping accretionary beds (Fig.13). The imbricate pattern formed by the dipping beds is most easily seen in the alternating sandstone and siltstone. Sandstones are fine to medium-grained and are made chiefly of quartz with abundant disseminated organic detritus. Much of the organic material was deposited along bedding planes and has a "coffee grounds" appearance. The beds show flat, normally graded, and massive bedding, along with parting lineation (Balsley, 1982, p. 21). Other bedding structures found include occasional cross beds, hummocky cross stratification, interference ripple marks, and some directional ripple marks. Soles of beds often have flute and groove casts. Beds are thickest at the top of the sandstone bar, and thin when followed seaward, down section. Bioturbation is moderate to heavy in the upper portions of the beds. Trace fossils identified are Ophiomorpha, Thalassinoides, and annelid worm smooth tube burrows. Generally this sandstone bar is overlain by a meter of fine-grained marine sediments and a thin (0.2 m) coal bed. The tongue, as just described can be followed from Straight Canyon to Alkali Creek (Fig.7). Balsley, (1982, p. 55) stated that lithologies III and IV are sometimes replaced laterally by these imbri- cate-bedded "distributary mouth bars" or distributary sheet sands. From Alkali Creek east, the bar probably grades laterally into interbedded siltstone and sandstone.

Six Aberdeen Sandstone bars are seen in the western wall of Coal Creek Canyon (Fig.14). The fifth and fourth sandstones from the base have been incised by a distributary channel that cuts through the fifth sandstone and into the upper lithologic unit of the fourth sandstone. The channel was subsequently filled with sandstone and siltstone. The six sandstones change somewhat when followed up Coal Creek to the mouth of Hoffman Creek (Fig.15). Six sandstones persist, but the second sandstone exhibits lithologies I and II instead of the imbricate bedding so well defined to the south near the front of the Book Cliffs. Fluvial crossbedded sandstone is found near the top of the upper sandstone at the Knight Ideal Mine (Fig.16). Rocks of the Aberdeen Member exhibit upper shoreface, foreshore, distributary channel, and distributary sheet sand environments, in additon to the offshore, transition, and lower shoreface environments described in the Spring Canyon Member. The upper shoreface environment is represented by rocks of lithologic unit III, and the foreshore environment is represented by rocks of lithology IV. Distributary sheet sandstones occur also in the Aberdeen Member (Fig.13). These sandstones are seaward dipping and arranged in an imbricate pattern. They do not display transition, lower and upper shoreface, and foreshore deposits, thus being distinguished from the delta front sandstones. Deposition occurred adajcent to distributary channel complexes in the Cretaceous Aberdeen deltas. Distributary sheet sandstone deposits represent high energy subaqueous flows (turbidites) that originated in river mouths and fanned out probably during times of flood (Balsley, 1982, p. 130). Distributary channels, as seen in sandstones of the Aberdeen Member (Fig.14), were incised into the shoreface sandstones by distributary streams that shifted across ancient delta plains (Balsley, 1982, p.131). The channel recognized at the mouth of Coal Creek Canyon represents a low sinuousity meandering stream that was abandoned and filled with sandstone and siltstone (Balsley, 1982, p. 162). Other possible ancient distributary channels associated with the Aberdeen Member (Fig.16) represent active fill of highly sinuous meandering streams on the delta plain. Barrier bars or wave--dominated deltas have been considered to be the main environments of deposition for the sandstones of the Aberdeen Member and Blackhawk Formation. Young (1955, 1957, 1966, 1973, 1976) stated that the depositional environment of the littoral sandstones in the Blackhawk Formation is predominantly barrier island bars with associated lagoonal deposits. He has also stated that some of the sandstones may have been deposited in deltas. Others (Anderson, 1978; Balsley, 1982) have stated that Blackhawk Formation littoral sandstones represent predominantly deltaic and associated delta strandline environments, with minor barrier bar deposits.

I agree with Balsley's conclusions that the Blackhawk littoral sandstones in Deadman Canyon Quadrangle represent ancient wave-dominated deltas. The presence of distributary channels and distributary sheet sands support the wave--dominated delta idea. Distributary channels and distributary sheet sands similar to those in the Aberdeen Member have been recognized in the Panther Sandstone and have been interpreted as deltaic deposits (Howard, 1966, p. 31). Other evidences for wave-dominated deltaic environments in the Blackhawk Formation on will be discussed further in this paper. In general, the Aberdeen Member displays a major regression of the Mancos Sea during Late Cretaceous time. Four to six major deltaic tongues prograded seaward over the area now enclosed in the Deadman Canyon Quadrangle. Each regression repre- sented by the sandstones was followed by a minor transgression of the sea over the area. Two other Aberdeen tongues exhibit rocks that were deposited off- shore from deltas situated west of the quadrangle. Coals on top of the lit- toral sandstones show that minor coal swamps developed on the littoral sand- stones before the next transgression took place.

Kenilworth Member.

The Kenilworth Member was named by Young (1944, p. 184) for exposures of the member near Kenilworth, Utah, 3 km west of the Deadman Canyon Quadrangle. He originally defined the member as consisting of a basal thick sandstone and overlying coal-bearing rocks (1955, p. 185). Later, Maberry (1971, p. 23) redefined the Kenilworth Member as consisting of basal interbedded siltstone and sandstone and a massive cliff-forming sandstone, only the lower part of the member as described by Young. I have followed Maberry's usage and have subdivided the Kenilworth Member into a basal siltstone or shale grading upward into a massive cliff-forming sandstone. The Kenilworth Member is mappable from near Helper, Utah eastward to the Beckwith Plateau (Maberry, 1971, p. 23), and crops out as a nearly vertical cliff with a lower slope-forming unit throughout most of the mapped area. Maximum thickness of the Kenilworth Member is 44 m where measured at Deadman Canyon. The member thins eastward from Deadman Canyon to Coal Creek, but thickens again to the east where it is 42 m thick at the eastern edge of the quadrangle. Lower contacts of the Kenilworth Member are placed at the top of the uppermost Aberdeen sandstone. This is usually marked by a break from a nearly vertical cliff to a slope. The upper contact is mapped at the top of the Kenilworth sandstone. The Kenilworth Member is composed of a basal slope-forming unit and an overlying thick sandstone. The lower slope portion changes laterally from siltstone, mudstone, sandstone, and coal at Deadman Canyon to predominantly siltstone east of Coal Creek (Fig.7). Fine-grained clastic rocks are medium grayish brown in the lower portion of the slope, and silty shale is medium gray in the upper and eastern part of the slope in the quadrangle. Coals in the member include the Castlegate "A" and "B" seams. Sandstones are fine to medium-grained, contain varying amounts of organic detritus, are thin bedded, and form minor ledges in the lower portion of the slope. The upper massive sandstone coarsens upward and contains four lithologic units like those previously discussed (Fig.17). This tongue or bar is similar to the uppermost Aberdeen Sandstone with respect to lithology, grain size and compostion, bedding structures, color, and trace fossils (Fig.18). Five general depositional environments are represented in the Kenilworth Member in Deadman Canyon. They are prodelta, delta front and beach sands, delta margin paralic swamps, delta plains and lower coastal flood plain. The prodelta environment is similar to that discussed for the Spring Canyon Member. Rocks that accumulated in this environment consist of gray shales and siltstone that generally grade upward to the interbedded siltstone and sandstone of the transition environment. These prodelta rocks usually form a slope at the base of the massive Kenilworth cliff. Transition, lower and upper shoreface, and foreshore or beach environments are represented by lithologic units I through IV. These environments are displayed in the massive Kenilworth cliff that crops out continuously across the quadrangle. I believe this sandstone represents shore and nearshore deposits of a wave-dominated delta system, like several of the underlying Aberdeen sandstones. Delta margin paralic swamps are represented chiefly by fine-grained fossiliferous, brackish water deposits, such as mudstone, siltstone, sandstone, and also minor lenticular coal. These swamps probably formed along the flanks of the Blackhawk deltas in such a way that they were partially protected by isolated sand bars or marginal strandlines, yet, they were open to the sea. Salt marshes formed in these brackish water delta- -flanking areas, and as a result, narrow lenticular coals were deposited (Balsley, 1982, p.178). Rocks of this environment are found at Deadman Canyon, however, they grade laterally into rocks of the prodelta environment or littoral sandstones before reaching Coal Creek (Fig.7). The Castlegate "A" and

"B" coals were probably deposited in a delta plain environment (Balsley, 1982, p. 183). Delta plain coals are often very extensive (20 to 30 miles wide) and reach thicknesses of up to 6 m. Generally coals of the delta plain environment are overlain by sediments of the lower coastal plain fluvial environment or paralic swamp sediments in the Deadman Canyon Quadrangle. Coals of the delta plain environment lie directly on or within a few meters of the top of the foreshore sands of the massive littoral sandstones. This also suggests a deltaic depositional environment for the littoral sandsotnes instead of barrier island and lagoonal environments. If this were a barrier island lagoonal sequence one would expect to find lagoonal filling deposits on top of the littoral sandstones, followed by coal desposition. Instead, coal is often deposited directly on the sandstone, which suggests coal swamps formed almost directly on the littoral sandstones. Coastal plain environments are characterized by lenticular and tabular channel fill sandstones, carbonaceous siltstones, mudstones, and coals in the Deadman Canyon Quadrangle. The sandstones represent meandering stream channel deposits, fine clastics represent overbank flood deposits, and coal was deposited in poorly drained backswamp areas (Balsley, 1982, p. 178). Generally coals deposited in a coastal plain environment are thin, and very lenticular, but can reach local thicknesses of 2.5 m (Balsley, 1982, p. 185). Coals are thinner, less frequent, and are replaced by oxidized overbank deposits the farther away from the paleoshoreline one travels. Rocks of this environment grade laterally into prodelta or littoral rocks before reaching Coal Creek in the lower Kenilworth Member in Deadman Canyon Quadrangle (Fig.7).

Lower Mudstone Member.

The lower mudstone member was originally assigned to the Kenilworth Member by Young (1955, p. 184), but Maberry (1971, P. 23) split the Kenilworth into two distinct parts. The old basal sandstone, as now used, is the Kenilworth Member, and the overlying slope zone is the lower mudstone member. The latter has been mapped as the slope interval between the massive Kenilworth Sandstone and the overlying cliff-forming Sunnyside Member. Lower contacts of the lower mudstone member are sharp and placed at the top of the Kenilworth Sandstone where there is a break from cliff to slope. Upper contacts are gradational and mapped near the base of the Sunnyside sandstone cliff. The member was mapped separately at Sunnyside, Utah (Maberry, 1971) and can be traced westward towards Helper where it generally forms a slope interupted by ledges of several thick channel fill sandstones. This member is most commonly clinkered or oxidized due to burning of underlying coal. The lower mudstone member consists of mudstone, shale, siltstone, sandstone, and coal. Basal parts of the member contain mostly fine-grained, carbonaceous clastic sediments, mudstone and siltstone, that weather medium grayish brown to medium dark gray. Main coals of this member are the Kenilworth, Gilson, Fish Creek, and Rock Canyon coal zones, in ascending order. The Kenilworth coal seam lies either directly on or within a few meters of the top of the Kenilworth Sandstone. The coal is usually overlain by mudstone and interbedded sandstones. Sandstones are fine to medium--grained, weather to a medium pale yellow orange, are usually very thin bedded and lenticular, and contain oscillation and directional current ripples. Sandstones are fine to medium-grained, and weather to a medium pale yellow orange. Several bivalves were found in the lower third of the member above the Kenilworth coal and include Corbula, Ursirvus, Anomia, and Brachiodontes. Crassostrea occurs in sandy beds (Balsley, 1982, p. 172), and a gastropod (probably Viviparus) is also found in this zone. Bivalves are brackish water elements and the gastropod is a fresh water genus, which was probably transported into the area by streams. The zone containing these fossils is consistantly within 2 m of the Kenilworth coal bed. Bioturbation is minimal, with trace fossils being indistinguishable. The Gilson coal zone lies above these fossiliferous and relatively fine-grained rocks. Siltstone, mudstone, thick sandstones and many thin to thick-bedded coal seams occur above the Gilson bed. Mudstone and shale are medium dark gray and carbonaceous. Sandstones weather medium gray orange and are fine to medium-grained (Fig.19). The sandstones are thin to medium bedded, lenticular, and exhibit trough cross beds, directional ripple marks, occasional cut-and-fill structures, and contorted bedding, perhaps produced by soft sediment deformation. Plant fossils, such as Araucaria and Sequoia, occur in some of the sandstones. Three-toed dinosaur tracks and logs of trees are found in the sandstone that overlies the Gilson seam in the Pinnacle Mine at Deadman Canyon.

Other major coal seams in this part of the member are the Fish Creek and Rock Canyon Coals, along with many laterally discontinuous and uncorrelatable coal seams. Seams are usually highly variable in thickness from one place to the next. Above the Rock Canyon coal zone is a thin belt of medium gray siltstone that is interbedded with minor sandstone. This belt of rock underlies the cliff-forming Sunnyside Sandstone. Paralic swamp, delta plain, and coastal plain environments are represented in the lower mudstone member of the Blackhawk Formation in Deadman Canyon Quadrangle (Fig.7). Coal of the delta plains environment (Kenilworth coal zone) is generally overlain by shale and mudstone of a paralic swamp environment. These rocks are, in turn, overlain by sediments of a coastal plain environment. Coastal plain sandstone, shale, and coal occur between the Gilson and Rock Canyon coals in the lower mudstone member of Deadman Canyon Quadrangle (Fig.19). A thin interval of restricted marine rocks occur above the Rock Canyon coal and below the Sunnyside Member in the quadrangle.

Sunnyside Member.

Young (1955, p. 185) defined the Sunnyside Member as consisting of a massive basal sandstone and overlying coal-bearing rocks. Maberry (1971, p. 27) redefined the member as including only the basal cliff-forming sandstone of Young's original definition, called the overlying rocks the upper mudstone member. This restricted Sunnyside Member consists of basal interbedded siltstone and sandstone that grade upward to a massive sandstone cliff.
I have mapped the Sunnyside Member using Maberry's criteria. The lower contact is gradational and placed at the base of the Sunnyside cliff and the upper contact was mapped at the top of the massive Sunnyside sandstones. Anderson (1978, p. 111) concluded that the Sunnyside Member contains two stacked regressive tongues in the Pine Canyon Quadrangle, and that the upper, less continuous, tongue has its west ernmost beginning between Coal Creek and Soldier Creek Canyons. However, I was able to map this upper sandstone to Deadman Canyon, and it probably continues westward into the adjoining Helper Quadrangle for some distance (Fig.20). The Sunnyside Member is thickest in the quadrangle near Deadman Canyon, where it reaches a maximum of 19 m, and it thins eastward to about 17 m near Soldier Creek. Two regressive littoral sandstone bars comprise most of the Sunnyside Member (Fig.7), which show transition, shoreface, and foreshore environments. A thin layer of restricted marine rocks generally occurs between the two regressive sandstones. The Sunnyside Member records deposition of a prograding delta followed, by a local minor transgression and then by progradation of another delta sequence.

Upper Mudstone Member.

The upper mudstone member was originally part of the Sunnyside Member (Young, 1955, p. 185), but Maberry (1971, p. 27) considered the coal-bearing rocks above the Sunnyside sandstone as a distinct upper mudstone member. Maberry's definition is used in this paper. The lower contact of the upper mudstone member is sharp and placed at the top of the uppermost Sunnyside sandstone, but the upper contact with the Castlegate Sandstone is possibly unconformable. This upper contact was generally mapped at the base of the Castlegate cliffs or where coarse-grained, light gray sandstone becomes dominant. Thickness of the uppper mudstone member in the quadrangle ranges from 80 m at Alkali Creek to 53 m near Coal Creek. The upper member is similar, lithologically, to the lower mudstone member, except for an occasional marlstone bed and occurrences of ironstone concretions in the upper member. Mudstone, siltstone, and shale are carbonaceous and weather medium brownish gray. Sandstones are fine-grained, mostly quartz, calcareous, usually flat and cross bedded, weakly bioturbated, and show soft sediment deformation. Most beds are lenticular and thin to thick bedded. The main coal seam in the member is the lower Sunnyside bed, which lies directly on or within a few meters of the top of the Sunnyside Sandstone. This is the only minable seam in the member in the quadrangle. Other coal seams are too thin and lenticular to be economically exploited. Much of the outcrop belt of this member has been clinkered by burning of the coal.

Rocks of the upper mudstone member were deposited almost exclusively in a coastal plain environment (Fig.7), but minor paralic swamp, and delta plain deposits are also represented in this member in the quadrangle. The Sunnyside coal was probabaly deposited in a delta plain environment. Rocks of the paralic environmnent are found above the second Sunnyside littoral sandstone in the upper mudstone member just west of Soldier Creek Shales, mudstones, and sandstones in the upper mudstone member are very similar to those described for coastal plain deposits in the lower mudstone member, except minor marlstones or calcareous siltstones and ironstone concretions are found in the upper mudstone member. The marlstones are probably associated with lacustrine sediments deposited in the flood plain and the ironstone concretions may have formed as bog iron in backswamps of the flood plain.

Castlegate Sandstone

Where exposed, the formation generally forms a cliff above the Blackhawk Formation. The contact with the overlying Price River Formation is conformable, and has been drawn where the slope-forming interbedded siltstone and sandstone of the lower Price River Formation first appear. The Castlegate Sandstone is 123 m thick at the type section in Price River Canyon, and thickens to the northwest where it reaches a maximum thickness of 185 m near Benion Creek (Van de Graff, 1972, p. 569). It is 77 m thick in Deadman Canyon, but no marked thickening or thinning of the formation is noted within the quadrangle. Predominant lithology is sandstone with minor amounts of interbedded shale and siltstone. Sandstones are medium to coarse-grained, and are composed mostly of quartz with varying amounts of clay minerals, chert, and other lithic fragments. Most common types of cement are silica, calcium carbonate, and some minor iron oxide. Lenticular bedding, trough cross beds, and current ripple marks are very apparent in the Castlegate Sandstone through- out most of the area. In places, the Castlegate Sandstone is very rich in par- ticulate organic material, and wood fragments up to 0.3 m long were found loc- ally. Generally the siltstone and shale beds are very carbonaceous, and some- times minor lenses of coal occur interbedded in these fine-grained rocks. Spieker and Reeside (1925, p. 446) dated the Castlegate in the Wasatch Plateau as late Montanan. The Castlegate Sandstone was deposited in a fluvial environ- ment (Van de Graff, 1972). Most beds appear as braided stream deposits in Wasatch Plateau and western Book Cliffs outcrops. From Deadman Canyon east- ward, the sandstone grades from a fluvial sandstone facies until it is in lit- toral facies near Green River and Thompson, Utah (Grant Willis, personal com- munication, 1983).

Price River Formation

In the Deadman Canyon area the Price River Formation has been subdivided into lower and upper unnamed members. The formation crops out in the Book Cliffs and Wasatch Plateau, and in an east-west belt across the northern part of Deadman Canyon Quadrangle. The lower member is a slope former, and the up- per member holds up two to three main ledges that locally form a single massive cliff (Fig.20). The Price River Formation is 200 m thick at the type section in Price River Canyon, and thins to 125 m in Coal Creek Canyon in the central part of the quadrangle. Thicknesses increase eastward so that near Thompson, Utah the Price River beds are 650 meters (Howard, 1966, p. 15). No marked thinning of the formation was noted in the Deadman Canyon Quadrangle. Regional changes in thickness have been attributed to intertonguing with the Mancos Shale, local warping, and pre-Tertiary erosion (Howard, 1966, p. 15). Spieker and Reeside (1925, p. 445) defined the upper contact of the Price River Form- ation as represented locally by a conglomerate of limestone pebbles. Clark (1928, p. 21) stated that the contact between the Price River and North Horn Formation is unconformable and marked by a basal conglomerate in most places. The contact is gradational and marked by the first appearance of red beds in Price River Canyon (Young, 1957, p. 187). Spieker (1946) placed the upper con- tact of the Price River Formation at a level of greatest lithologic change be- tween the thicker sandstones of the Price River Formation and the varigated mudstone beds of the North Horn Formation. I have used Spieker's (1946) de- scription of the contact for the formation and mapped the top of the Price River beds at the level of greatest lithologic change between lower sandstone and upper fine-grained clastic rocks. This is usually expressed as a break in slope from cliff-forming sandstone up into slope forming shales. It is diffi- cult to use the first occurrence of red beds as the contact because these red beds are usually covered, except in fresh road cuts. Several limestone rip-up conglomerates occur in the section, but it is difficult to correlate these beds because of their lenticularity. The Price River Formation consists principally of sandstone with varying amounts of interbedded siltstone, shale, and mud- stone. Lithologically, the formation is similar to the Castlegate Sandstone, but with greater thicknessess of fine clastic rocks. This difference in litho- logy is shown by the cliff-forming Castlegate Sandstone contrasted to the slope-forming lower Price River Formation. Abbott and Liscomb, (1956, p.122) and Cobban and Reeside (1952) have assigned a Campanian to Maestrichan age to the Price River Formation. Spieker (1946) stated that the rocks probably change from late Montanan to early Lancean somewhere in the upper Price River Formation. The Price River Formation represents deposits of fluvial environ- ments in the Deadman Canyon area. Mudstones and other fine-grained clastic rocks were probably deposited on floodplains as overbank deposits during times of flood. Thick sandstones of the formation possibly represent a general braided stream environment, although lenticular sandstones associated with the fine-grained rocks are probably chan- nel fills of meandering streams on a flood plain.

Lower Price River Member.

This member is predominantly mudstone, siltstone, and shale, with interbedded sandstone. Fine clastic rocks are very rich in particulate organic material. Most units are medium gray to medium brownish gray. Mudstones and siltstones are often very thin bedded to laminated. In freshly cut banks, siltstones show directional ripple marks, and paleocurrents associated with these siltstones generally trend toward the east. Interbedded shale contains minor beds of lenticular coal, generally thinner than 0.5 m. Sandstones are fine to coarse-grained, and consist mostly of quartz with varying amounts of feldspar, chert and other lithic fragments. Many of these sandstone beds are lenticular and are thin to medium bedded. This member exhibits a stairstep alternating ledge and slope exposure. Thickness of the member ranges from 42 m at Deadman Canyon to 50 m at Clearwater Creek.

Upper Price River Member.

The upper member consists of sandstone with very minor amounts of shale. Sandstones are coarse to medium-grained, displaying an apparent fining upward trend. Colors range from medium gray brown to medium light gray. Sandstones are medium to thick bedded, and contain lenticular beds, cross stratification, and ripple marks (Fig. 21). Shale in this member is carbonaceous, and medium gray. This shale is interbedded with thick-bedded, cross stratified sandstone just described. The member is 77 m thick in Coal Creek Canyon.

Cretatceous-Tertiary Systems

North Horn Formation

The North Horn Formation weathers to a slope interrupted by ledges of channel fill sandstones and limestone. It is mainly mudstone, and shale, with interbedded thin marlstone, limestone, and sandstone (Fig.22). Minor coal beds occur in the formation in Price River Canyon, but none are exposed in the Deadman Canyon Quadrangle. I have divided the formation into two informal members. The lower member generally has more interbedded sandstone and is coarser grained and less calcareous than the upper member, which has minor interbedded limestone. At the type section, Spieker (1946, p. 133) measured the formation as 508 m thick. To the east,in Price River Canyon, the formation thickens to 677 m. The North Horn Formation ranges from 337 m thick at Deadman Canyon to 309 m thick just west of Soldier Creek Canyon in the quadrangle. Fossils were collected from the North Horn Formation in the mapped area, including some fresh water bivalves and gastropods and some fossil leaf fragments. Vertebrate fossils have been collected from the North Horn Formation (Spieker, 1946, p. 134). Paul Anderson (personal communication, 1983) found a bone of a vertebrate organism (possible alligator) in the Pine Canyon Quadrangle. Fossils collected from the formation indicate that it includes Cretaceous and Tertiary rocks, but it is difficult to draw the boundary between the two systems. It generally is agreed, however, that the lower part of the formation is Late Cretaceous and the upper part is Early Paleocene. The contact between the North Horn Formation and overlying Flag- staff Formation is gradational. I have placed the contact immediately below the fossiliferous, relatively clean, blue gray limestones that appear to be continuous beds.

Lower North Horn Member.

As already mentioned rocks in this member are coarser grained and less calcareous than those in the overlying member. The lower unit consists of gray shale and mudstone interbedded with thin beds of grayish orange, medium-grained to locally conglomeratic, sandstone. The minor sandstones in this argillaceous member contain quartz, lithic fragments, limonite, and weathered feldspar, and appear subarkosic. This part of the member forms a gentle to moderate slope. More than half of the upper part of the lower member consists of sandstone that weathers medium dark orange brown to gray orange or very light gray, and generally has a salt-and-pepper appearance. Sandstones are medium-grained on the average, but range from fine-grained to conglomeratic rocks that contain fine pebble-sized clasts. Sandstones contain quartz, lithic fragments, weathered feldspar, and some clay pebbles or rip-up fragments that give sandstones a conglomerate appearance. The sandstones are thin to thick bedded and contain trough crossbeds sets that are 0.2 to 0.5 m high. These lenticular units are difficult to trace laterally for more than a few tens of meters (Fig.23). They contain wood fragments and disseminated carbonaceous material. The upper sandy half of the lower member usually forms a steep slope or cliff be low the slope-forming upper member. The only fossils collected in this member are partial leaf imprints found in thin bedded sandstone at Clearwater Creek. Maximum thickness of this member is 149 m near Deadman Canyon, and the member thins eastward to 133 m near Soldier Creek. The lower member was deposited in flood plain environments (Osterwald, et al., 1981, p. 23). Fine-grained rocks were probably deposited as overbank flood sediments, and the lenticular sandstone beds represent channel fill deposits, probably of meandering streams.

Upper North Horn Member.

The upper member forms a gentle to moderate slope between the sandstones of the lower unit and the resistant cuesta-capping limestones of the Flagstaff Formation. Maximum thicknesss of the member is 198 m at Clearwater Creek, and minimum thickness is 158 m just west of Soldier Creek Canyon. This member consists of interbedded mudstone and shale, with minor sandstone, and limestone. Mudstone and shale in the lower few meters of the member are pale yellowish orange, and those in the upper parts are variegated and red. Argillaceous rocks weather to form a slope. Float on these slopes consists of sandstone, limestone nodules, and a few oncoids. Limestone nodules are medium gray, and at first glance appear like oncoids. When broken open the nodules have no concentric banding, are micritic, and contain some silt. Sandstones in the upper member are similar to those in the lower member, but are usually more calcareous. Two or three main sandstone ledges consistantly have a basal limestone pebble conglomerate (Fig.24). Pebbles in the conglomerates are spherical and are comparable to clay rip-up clasts. Matrix of the conglomerate consists of coarse-grained sand and highly calcareous siltstone. Limestone clasts, which have weathered out, look much like limestone nodules found elsewhere on the shale and mudstone slopes. Limestone is much more abundant in upper parts of the section. It is usually pale yellowish orange, but one or two beds are dark gray. Sand, silt, and argillaceous material occur in the limestones and make up 15 percent of the rock. Fossil bivalves and gastropods are found in some limestone lenses. Beds of limestone are less than one meter thick. The upper member accumulated in mixed lacustrine and fluvial environments. Sandstone and mudstone are similar to those found in the lower unit, but the addition of limestone containing fresh water bivalves and gastropods indicates a greater development of lacustrine environments in the upper part. Thus, the environment of depostion is interpreted to have been a low-lying inland flood plain with meandering streams and occasional lakes.

Tertiary System

Flagstaff Formation

The Flagstaff Formation consists of interbedded limestone, shale, sandstone, and some oil shale at the type locality in the Wasatch Plateau. Gilliland (1951, p. 25,26) used the term Flagstaff Formation in western exposures instead of Flagstaff Limestone because he found great thicknesses of sandstone and conglomerate in the formation. Others, such as McGookey (1960, p. 596), La Rocque (1951, 1960), Runyan (1977, p. 71), and Anderson (1978, p. 45) have also used the term Flafstaff Formation. Ryder, et al. called the Flagstaff Limestone the Flagstaff Member of the Green River Formation in their study of the Uinta Basin (1976, p. 496,497). In the Deadman Canyon Quadrangle, the rocks in the Flagstaff interval are different than those described at the type section; therefore, I will call the formation the Flagstaff Formation. The formation is described as 300 m of limestone that forms high cliffs and parapets at the type area. However, the formation thins considerably to only approximately 80 m in the western part of Deadman Canyon, where it crops out as a series of three or four limestone ledges, and forms a stripped surface and dip slope between the crest of the Book and the base of the Roan Cliffs. Contacts are gradational between the North Horn and Flagstaff formations and between the Flagstaff and Colton formations. The lower contact was mapped at the base of laterally persistant beds of clean, medium gray, fossiliferous limestone, and the upper contact was mapped at the top of the uppermost persistent limestone, where red mudstone and fluvial sandstones become prominent. Spieker (1949, p.13) assigned a Late Paleocene age to the Flagstaff Formation, and LaRocque (1951) suggested that the formation is Eocene in age. LaRocque later concluded (1960, p. 73) that the lower member is Middle and Upper Paleocene and the upper member is Lower Eocene. The Flagstaff Formation in the Deadman Canyon Quadrangle consists of interbedded mudstone, shale, limestone, and sandstone (Fig.25). Mudstone and shale are common in the lower and upper parts of the formation. They are usually variegated, red, or green, and form slopes. Ledge to cliff-forming sandstone occurs in the slope and ranges from pale olive gray to moderate grayish brown. Sandstones are medium to coarse-grained, show fining upward, and are composed of quartz, abundant lithic fragments, and clay rip-up clasts. Most of the sandstones are medium to thick bedded and are lenticular (Fig.26). Crossbeds and cut-and-fill features are common bedding structures. Limestones are generally micritic and thin to medium bedded. They weather medium bluish gray to medium dark gray, and hold up ledges. Freshwater bivalves and gastropods are locally abundant in the limestones, here and elsewhere (La Rocque, 1960 and Osterwald, Maberry, Dunrud, 1981). The Flagstaff Formation was deposited in a freshwater lake and associated fluvial environments. Ryder, Fouch, and Ellison (1976, p. 499,500) proposed the term "lake--margin carbonate flat" for a depositional environment that has had extensive nearshore lacustrine carbonate sedimentation and some subaerial exposure. Characteristics of this facies are gray to green calcareous claystone, limestone mud and grain supported carbonates, and locally abundant channel-form sandstone beds. These charact- eristics apply generally to the the Flagstaff Formation of Deadman Canyon Quad- rangle.

Quaternary System

The Quaternary System is represented by Holocene and Pleistocene deposits in the quadrangle. Generally these are unconsolidated to poorly consolidated, show poor stratification, and vary in grain size from clay-sized particles up to blocks several meters in diameter. Quaternary deposits consist chiefly of alluvium, colluvium, slope wash, pediment gravels, and clinkered zones. Alluvium is composed of clay to block-sized clasts that have been eroded from bedrock in the area, and deposited in or near stream channels. Such material may be dark brown to dark gray where weathered from Mancos beds or reddish brown where from clinkered or weathered sandstones. The material is unconsolidated to slightly consolidated, and is thinto thick-bedded. Crossbedding may also be present locally. Thickness varies from place to place, but probably is not more than ten meters at any point in the quadrangle. Colluvium is made up of clay to boulder-sized material that has been transported down slope chiefly by gravity. Such material is pale yellow orange to medium brown in the quadrangle. Clasts are usually poorly sorted and angular to subrounded. Boulders and blocks are massive, attaining diameters of several meters. Colluvium is unconsolidated and covers slopes from the base of the Book Cliffs and partially covers bedrock on the face of the cliffs. Areas differentiated as slope wash consist of unconsolidated to poorly consolidated clay to sand-sized particles that have been washed into place by running water not confined to specific stream channels (Witkind, 1979). In the quadrangle it is generally derived from disintegration of Mancos Shale, and is light to medium gray. These accumulations may be thinly laminated, display crude cross stratification, and generally cover the broad valleys at the base of the gravel-covered Mancos Shale bluffs. Pediment gravels consist of pebbleto boulder-sized clasts with a matrix of sand and silt. Boulders in some gravel deposits are as large as 2 m in diameter. Clastic debris was derived from the bedrock that makes up the Book Cliffs. These gravels may contain crude channel deposits and a few lenses of clay material. Thicknesses range from 4 to 15 m, with the thickest and coarsest deposits closest to the Book Cliffs. An undulatory erosional surface under the gravels cuts across Mancos Shale and Panther Sandstone. The terrace-like gravel caps rise gently towards the Book Cliff escarpment. They may either slope up to meet the colluvium deposits at the escarpments or they may be truncated before reaching the colluvium-covered escarpment. Up to five different levels of pediment development and gravel veneer have been mapped in the Deadman Canyon Quadrangle. These different levels are best expressed in the Coal Creek area, near the old Young Ranch (Fig.27). Carter (1977, p. 714) concluded that similar levels cannot be regionally correlated from area to area along the Book Cliffs escarpment because the number of levels is so variable. Several ideas as to the origin of pediments and the different pediment levels have been suggested. Gilbert (1880) believed that the levels formed due to lateral planation of streams too heavily loaded with sediments to down cut. Rich (1935, p. 1013) believed pediments were formed by sheet wash, and the different levels were formed by dissection of previous pediments due to climatic changes, regrading by escarpment retreat, and possible tectonic uplift. Carter (1977, p. 714) concluded that pediments are produced by valley cutting and widening due to stream erosion and that the different levels form by stream capture followed by agradation and subsequent regradation. This seems the most probable model for pediment development in the Deadman Canyon Quadrangle. Areas that have been burned or clinkered are restricted to the coal-producing members of the Blackhawk Formation (lower and upper mudstone members and Lower Kenilworth Member). From a distance the rocks have a characteristic moderate red color. Upon closer inspection the sedimentary rocks appear clinkered and baked. The burn zone is generally restricted to near the outcrop, but may extend underground up to several hundred feet in from the projected coal outcrops (Michael Glassen, personal communication, 1982).

STRUCTURAL GEOLOGY

Structure of the Deadman Canyon Quadrangle is dominated by flank dips northward off of the San Rafael Swell. Strike trends are roughly parallel to the Book Cliffs escarpment, and range from north 90 degrees West, at Deadman Canyon, to north 84 degrees west near Soldier Creek Canyon (Fig.28). Dips range from 4 to 7 degrees toward the north, and generally increase slightly from west to east. Faulting in the quadrangle is minor. No major faults were mapped, and those observed have only a few meters of displacement. Spieker (1946, p. 156) stated that monoclinal folds of the Colorado Plateau in Utah (including the San Rafael Swell) were formed before deposition of the Flagstaff Formation. Possible thinning of the Price River and North Horn sections in the Deadman Canyon Quadrangle, when compared with adjacent areas to the east and west, suggest that uparching of the San Rafael Swell was contemporaneous with deposition of Price River and North Horn sediments. However, data are insufficient to draw any firm conclusion presently, and detailed analysis of several additional stratigraphic sections outside of this quadrangle will be required to document any pattern.

ECONOMIC GEOLOGY

Coal is the main economic product of the Deadman Canyon Quadrangle. Building materials and water resources will be required as exploitation of coal and petroleum continues. Several other coal mines have operated in the quadrangle. The Knight Ideal Mine in Coal Creek Canyon was worked for several years before closing in the early 1970's. Several mines have operated in Deadman Canyon in the past, but at present, the Pinnacle Mine is the only operating mine in the quadrangle. Three seams have produced most of the coal taken from the mines in the area: the Castlegate "A", Gilson, and Lower Sunnyside seams.

Oil and gas exploratory wells were drilled in the southern half of the quadrangle, near Deadman Canyon and Coal Creek Canyon. Further coal and petroleum development will necessitate upgrading of local roads.

An abundant supply of road metal is available in the pediment gravels of the area.

Local springs and intermittent and perennial streams can supply some of the water needed for resource development.

Coal

Nine coal seams or coal zones have been identified in the Blackhawk Formation of Deadman Canyon Quadrangle (Clark, 1928, p. 36; and AAA Engineering, 1979, p. 5) of which only three or four are potentially minable. Coal zones rather than individual seams were mapped because of the lenticularity of the seams. However, the terms "zone" and "seam" are used in- terchangeably in this study. Main coal-producing zones in the quadrangle occur in the lower part of the Kenilworth Member and lower and upper mudstone members of the Blackhawk Formation. Present minable coal seams include the Castlegate "A", Gilson, and

Lower Sunnyside zones, and nonminable coal zones are the Cas- tlegate "B", Royal Blue, Kenilworth, Fish Creek, Rock Canyon, and Upper Sunny- side zones. Many other thin, lenticular, and unnamed coal seams are present in the quadrangle. Coal zones I mapped include the Castlegate "A", Castlegate "B", Kenilworth, Gilson, Rock Canyon, and Lower Sunnyside beds.

At present, the Gilson and Lower Sunnyside zones are being mined, and plans are underway to mine the Castlegate "A" seam in Deadman Canyon (Michael Glassen, personal communication, 1983). Thinner seams are not, at present, economical to mine. However, they may be economically mined or may be targets for in situ coal gasification projects in the future. Samples (Doelling, 1972) from the Gilson seam at Knight Ideal Mine were analyzed for moisture, volatile matter, fixed carbon, ash, sulfur, and BTU per pound. Statistics for these factors were averaged for the 137 samples taken, and the coal is classified as high-volatile bituminous B rank, based on these averages (American Society for Testing and Materials, 1977). Total coal reserve tonnage (in short tons) has been estimated at 4,700, 000 tons for five minable coal seams (AAA Engineering, 1979, p. 10). The coal zones included in this estimate are the Castlegate "B", Lower Sunnyside, Gilson, Kenilworth, and Castlegate "A" beds, in order of decreasing tonnage. Guidelines followed for tonnage estimation were set by the U. S. Bureau of Mines and U. S. Geological Survey (1976). Minable thickness of coal seams with splits was calculated and used for the construction of isopach maps. This thickness was computed by subtracting the thickness of a split in a coal seam from the thinnest coal directly above or below the split. The computed thickness was then added to the other adjacent thicker coal. Thus, total minable coal thickness is found by adding the thickness of the best coal seam to that of the calculated thickness of an adjacent thinner seam. Coal development in the future will continue principally through subsurface mining, and possibly in situ coal gasification. Surface mining can probably be ruled out in the quadrangle because of the rugged topography, and high amount of overburden. Potential is good for additional subsurface development of coal in the quadrangle. All areas of unleased Federal coal land in the quadrangle have high development potentials (AAA Engineering, 1979, p. 11). This means that coal beds are at least 1.5 m thick and covered with no more than 300 m of overburden in a given area. Data for determining coal gasification potential are incomplete at present, so no estimates are available. Because of the number of coal seams in the quadrangle, however, coal gasification will undoubtedly be considered in the future.

Castlegate "A" Coal Zone

This coal lies above the Aberdeen Member in the basal slope-forming zone of the Kenilworth Member. The Castlegate "A" seam can be mapped from the Deadman Canyon Quadrangle westward about 20 miles (Clark, 1928, p. 30). Most of the thickness information comes from outcrop measurements, for subsurface data are limited (Fig.29). Generally the coal zone is thickest in the west and north and thin in the eastern part of the quadrangle. The coal is lensing and reaches a maximum thickness of .8 m (5.8 ft) just west of Straight Canyon. From Straight Canyon eastward, the coal generally thins until it pinches out near Alkali Creek. Average thickness of the coal zone is 1.1 m (3.5 ft). Burning of this zone at and near the surface is restricted to the western part of the quadrangle. The interval between this coal zone and the overlying Castlegate "B" coal zone is 2 to 10 m (7 to 35 ft). Data from measured sections indicate that the floor rock for the seam is sandstone and carbonaceous shale, and the roof rock is sandstone, siltstone, and carbonaceous shale.

Castlegate "B" and Royal Blue Coal Zones

These coals are located between the Castlegate "A" and Kenilworth coal zones. The seams have been mined in the Helper Quadrangle, to the west, and are restricted to the western half of the Deadman Canyon Quadrangle. Both coals are thin and lenticular, and only the Castlegate "B" coal zone reaches minable thicknesses in the quadrangle. Average thickness of the Royal blue zone is 0.3 m (1 ft), and average thickness of the Castlegate "B" bed is 0.8 m (2.5 ft) (Fig.30). Maximum thickness of the Castlegate "B" is 4.0 m (13 ft) in a drill hole in the left fork of Deadman Canyon (Fig.30). Roof rock is mainly sandstone and siltstone and floor rock is siltstone and carbonaceous shale. The Castlegate "B" coal zone may possibly be developed in the future, but more extensive data are required to determine its reserves in the quadrangle.

Kenilworth Coal Zone

This zone lies consistantly within a meter or two of the top of the Kenilworth sandstone. The zone crops out nearly continuously across the Deadman Canyon Quadrangle, and has been mapped for 33 miles along the western Book Cliffs and northern Wasatch Plateau (Clark, 1928, p. 39). It is mined at Kenilworth, where it is 6 m (19 ft) thick. Coal of the zone has variable thickness due to the lenticularity of the bed, and is not found in some measured sections because of erosion of the Kenilworth coal swamp by Cretaceous streams, and possibly due to nondeposition of the coal. Average thickness of the seam is 0.7 m (2.3 ft) with a minimum measured thickness of 0.3 m (1 ft) and a maximum thickness of 1 m (3.5 ft). Generally the zone appears to be thickest west of Coal Creek and thins to the east (Fig.31).

Thickness of the interval between the Castlegate "A" and Kenilworth coal zone is between 55 and 75 meters (160 and 250 ft). Roof rock and floor rocks are mostly carbonaceous shale and sandstone.

The Kenilworth coal should be considered for possible future development, even though mining of this zone is not presently economical in the quadrangle.

Gilson Coal Zone

Clark (1928) suggested that the Gilson Coal is a split from the Kennilworth coal in the Helper Quadrangle. The Gilson zone extends from the Helper Quadrangle eastward across Deadman and Pine Canyon Quadrangles. This seam is considered the most important coal zone in the quadrangle (Doelling, 1972), and has been mined extensivly in Coal Creek and Deadman Canyons (Fig.32). Gilson coal is highly lenticular and variable in thickness within the quadrangle. Coal thickness ranges from 3 m (9 ft) at Coal Creek to under 1 m (3 ft) at several locations (Fig.33). The bed is approximately 2 m (6.5 ft) thick in the Deadman Canyon area, and thickens to 2.3 m (7.5 ft) to the east. The seam is thinner at outcrops in the southernmost escarpments of the Book Cliffs (1.3 m) and tends to thin considerably in the subsurface to the north (Michael Glassen, personal communication, 1982). A drill hole in the left fork of Deadman Canyon (Fig.33) indicates that the Gilson seam thins to only 0.5 m (1.7 ft). Measured surface coal sections display seam thickness of 2.3 m (7.5 ft) at Straight Canyon that thins to 1.2 m (4 ft) in Hoffman Creek. Outcrop and subsurface mine measurements, in part from Doelling (1972) show that the Gilson coal zone thickens again to a maximum of 3.4 m (11.1 ft) at Coal Creek. Drill holes in Coal Creek Canyon (Fig.33) document thinning of the Gilson zone to the north (1.5 m). Subsurface data are lacking east of Coal Creek, but measurements of outcrops suggest that the coal thickness averages approximately 1 m (3.3 ft)

there. Splits are a main concern in the Gilson coal. Boney splits and steep pitches of the coal beds make mining difficult and expensive in the Coal Creek area (Doelling, 1972). One main split, averaging 0.2 m thick, is recognized in the Deadman-Straight Canyon areas. Interburden thickness between the Gilson coal zone and the overlying Fish Creek coal zone ranges from 8 to 18 m (25 to 65 ft). Roof and floor rocks consist predominantly of sandstone and carbonaceous siltstone. Roof competency is very good in the Pinnacle Mine at Deadman Canyon. However, problems occur where the mine workings cross under a ravine or other surface drainage. The main roof problem is the occurrence of "kettle bells" (Michael Glassen, personal communication, 1982). "Kettle bells" are diagenetic, cone shaped, and slickenside features that fall from the roofs of coal mines in the Book Cliffs (Young, 1976, p12).
Continued development of this coal zone is promising in the future.

Fish Creek and Rock Canyon Coal Zones

These coal zones are very thin and lenticular in the Deadman Canyon Quadrangle. The belt of rock containing these two coal zones is usually extensively burned. Therefore, mapping and measuring the zones was difficult. Clark (1928) traced the Fish Creek coal from Fish Creek, east of Deadman Canyon Quadrangle, to just west of Soldier Creek Canyon and stated that the coal possibly extends farther west to Coal Creek. Coal in the Fish Creek zone is thin, no more than 1 m thick, and usually contains several splits. The Rock Canyon coal zone has been mapped from Rock Canyon, several km east of the Deadman Canyon Quadrangle, to just west of Coal Creek Canyon (Clark, 1928). Coal in the Rock Canyon zone is thicker than the Fish Creek coal. Maximum thickness of the former coal is nearly 1.5 m at Straight Canyon, and averages 0.9 m (2.9 ft) between Coal Creek and Deadman Canyon (Fig.34). The coal thins between Coal Creek and Soldier Creek, but thickens again at Soldier Creek, where it is presently being mined by Soldier Creek Coal Company. Generally roof and floor rocks consist of siltstone and minor sandstone for the Rock Canyon zone. The Fish Creek coal zone is usually 5 to 15 m (15 to 45 ft) above the Gilson coal zone, and the Rock Canyon coal zone is 5 to 15 m (15 to 45 ft) above the Fish Creek coal zone.

Subsurface and outcrop coal thicknesses generally are not available but limited data indicate that the Rock Canyon coal zone has some potential for future development, but the Fish Creek coal does not appear to hold much promise within the quadrangle.

Lower and Upper Sunnyside Coal Zones

The Lower Sunnyside coal zone has been mapped from Sunnyside, Utah across the Deadman Canyon Quadrangle and into the Helper Quadrangle (Clark, 1928). Coal in the Upper Sunnyside zone in the Deadman Canyon Quadrangle is correlated to the upper coal seam mined at Sunnyside, Utah. It is very lenticular, and has not been mapped nor extensively measured in the quadrangle. The Lower Sunnyside coal, however, has been mapped across the quadrangle mainly because of its position above the Sunnyside sandstone. The Lower Sunnyside coal is presently mined in Deadman Canyon, where it reaches a maximum thickness of about 1.5 m (5 ft). Outcrop measurements show that the Lower Sunnyside bed thins eastward from Coal Creek, and develops several major splits (Fig.35). Drill data indicate that the coal thickens to over 2 m in the left Fork of Deadman Canyon, and is a little over 1 m thick in the subsurface at Coal Creek. Interburden between the Kenilworth and Lower Sunnyside zones is between 60 and 80 m (190 and 250 ft). Floor rock is composed mainly of sandstone and carbonaceous shale, and roof rock is chiefly siltstone and shale with minor sandstones.

Potential for development of the Lower Sunnyside coal zone seems good. However, as with several of the other coal zones, more subsurface information is needed to get a better idea of the zone's economic potential.

Oil and Natural Gas.

Several wells have been drilled in the southern half of the quadrangle in search for oil and natural gas. The main targets were the Ferron and Emery sandstones. One well drilled near Deadman Canyon in 1956 had a show of gas. However, subsequent drilling in that area (Price no.3 well, NE1/4, NW1/4, Sec.19, T13S, R11E and Price No.5 well, NW1/4, SW1/4, Sec.20, T13S, R11E) yielded only dry holes. Two additional exploratory wells were also drilled in the Mancos Shale near Coal Creek (Coal Creek No.1, SE1/4, SE1/4, Sec.18, T13S, R11E, and Coal Creek No.2, SW1/4, SW1/4, Sec.10, T13S, R11E), but neither of these wells produced.

Homoclinal dips and unfaulted sections contain no known petroleum traps in the quadrangle. However, interfingering of the sandstones in the Lower Blackhawk and marine shales of the Upper Mancos Shale, could create stratigraphic traps for petroleum in areas to the north. Further exploration should be considered there.

Building Materials.

Unconsolidated gravel provides abundant material for road construction in the area. Several gravel pits have been developed in the pediment gravels along Utah State Highway 53 (SW1/4, NW1/4, Section 1, T14S, R11E). Other smaller gravel pits also have been opened along the roads leading to Coal Creek and Deadman canyons.

Water Resources.

One perennial stream and many intermittent streams occur in the Deadman Canyon Quadrangle. Coal Creek and several of its tributaries have flowing water all year. However, in late summer, the flow of the streams is minimal (except for flash floods). Intermittent streams as a rule flow only during the spring and early summer. Many springs are also active in the spring and early summer, but most dry up by the end of August. Coal Creek Canyon area has the greatest amount of water available for year around use.

SUMMARY

Mancos Shale accumulated in a Late Cretaceous shallow seaway that covered much of east-central Utah. Star Point Sandstone and tongues of the Spring Canyon Member of the Blackhawk Formation represent distal margins of wave-dominated deltas that prograaded eastward into the Mancos Sea. These sandstone tongues mark the beginning of regression of the Cretaceous sea from the Deadman Canyon area. Four to six stacked regressive littoral sandstones of the Aberdeen Member represent wave-dominated deltas, strandline deposits, and associated distributary channels and distributary sheet sands. Coal above the Aberdeen Member was deposited in delta plain swamps. Brackish water shale, siltstone, and sandstone overlie these delta plain coals. A minor transgression of the sea was then followed by deposition of the Kenilworth Sandstone that also represents progradation of a Cretaceous wave-dominated delta. The Kenilworth coal (delta plain environment) lies above the Kenilworth Sandstone, which in turn is overlain by fossiliferous mudstones, shales, siltstones, minor sandstone and coals of a paralic swamp environment. The Gilson coal zone lies above rocks deposited in a paralic swamp, and generally marks the beginning of sediments deposited in stream channels, backswamps, and lakes of a fluvial coastal plain environment. These conditions existed until a shale-producing marine transgression occurred again in the Deadman Canyon Quadrangle. Two stacked wave-dominated delta littoral sandstones of the Sunnyside Member mark the final retreat of the sea from the Deadman Canyon area. These regressive sandstones are overlain by coastal plain coals, and sandstone and mudstones of the upper mudstone member of the Blackhawk Formation.

The Castlegate Sandstone and Price River Formation represent predominantly fluvial deposits. These deposits have a western source; probably the Sevier orogenic belt. The Cretaceous-Tertiary North Horn Formation and Tertiary Flagstaff Formation represent deposition in fluvial-lacustrine and lacustrine environments respectively. Uplift of the San Rafael Swell possibly caused thinning of Price River and North Horn beds in the quadrangle. However, data are insufficient to be certain.

A thin veneer of Quaternary gravel and alluvium blankets pediments cut across much of the Mancos Shale exposure belt at the base of the Book Cliffs. These deposits are debris eroded from the retreat of the Book Cliffs escarpment. Three coal seams have been or are presently being mined in the quadrangle, including the Gilson, Lower Sunnyside, and Castlegate "A" coal zones. Future exploitation potential is good for these seams, as well as for the Castlegate "B" and possibly the Kenilworth and Rock Canyon coal zones. The Gilson seam averages 1.5 m (4.4 ft) thick across the entire quadrangle, but west of Coal Creek average thickness of this seam is 1.9 m (6 ft). Castlegate "A" (1.1 m, 3.3 ft) and the Castlegate "B" (0.8 m, 2.5 ft) coal zones are also thicker in the western half of the quadrangle. The Kenilworth coal seam averages 0.7 m (2.0 ft) thick across the quadrangle. Coal in the Rock Canyon zone averages 0.9 m (2.8 ft) from sections measured east of Straight Canyon. Further subsurface data are required to determine reserves of the thinner coal zones.

APPENDIX

Measured Sections

Flagstaff and North Horn formations

The section was measured near the head of the left fork of Deadman Canyon. Starting point was at the top of the Price River Formation cliff in the bottom of the canyon (SE1/4, SE1/4, Sec.1, T13S, R11E). The section was measured up the slope to the top of the cuesta-capping Flagstaff Formation that forms a dip slope north of the Book Cliffs escarpment (NE1/4, SE1/4, Sec.1, T13S, R11E).

Thickness(meters)

Unit Description Unit Cumulative

20. Mudstone, sandstone, limestone;. 45.5. 45.5.
mudstone,weathers medium gray and varigated, mostly covered slope; sandstone, medium gray, weathers gray brown, medium-grained, minor cross stratification, lense shaped channel fill sandstone, medium to thick bedded; limestone, medium gray weathers medium light gray, fossil fragments, mostly bivalves, forms slope with ledges.
19. Covered interval and limestone,. 10.5. 56.0.
slope is probably shale or siltstone, weathers medium gray; limestone, micritic, medium gray, weathers same, fossil fragments, bivalves and gastropods, forms slope with minor limestone ledges.
18. Sandstone, limestone; sandstone. 3.0. 59.0.
same as unit 1; sandy limestone, upper 1.5 m,fosiliferous micritic limestone, gastropod and bivalves, medium gray weathers medium blue gray, forms ledge.
17. Siltstone, limestone; siltstone is. 10.3. 69.3.
covered; soil weathers medium orange brown; limestone, medium blue gray, weathers medium brownish gray, sandy, very well indurated, gastropods and bivalves, 1 m thick ledge, forms slope and limestone ledges.

Base of the Flagstaff Formation and top of the North Horn Formation.

Total thickness of the Flagstaff Formation . . . 69.3.

16. Shale or siltstone, sandstone, and. 96.2. 96.2.
limestone; mostly covered interval, limestone and sandstone float; sandstone weathers pale yellow orange, very fine-grained; limestone float increases upward, and contains bivalve fragments, limestone, weathers medium brownish gray, silty, argillaceous, forms slope with minor sandstone and limestone ledges.

15. Sandstone, reddish brown in the lower part of the unit, medium pale yellow orange near the top, basal conglomerate, coarse to fine-grained, fines upward, clasts are calcareous, probable rip-up clasts, 8 mm to 1.3 cm in diameter, organic detrital material and coarse-grained sandstone lie on top of this conglomerate, angular grains, well crossbedded, cross bed sets about 0.4 to 0.5 m high-some less than 0.2 m, thick to medium bedded, forms cliff.

14. Siltstone, sandstone, and limestone;. 18.5. 129.2.
siltstone, forms mainly covered slope, weathers pale yellow orange; sandstone, medium pinkish gray, weathers medium brownish gray, calcareous, fine-grained; limestone, minor clay and 1% to 5% sand grains, medium light gray, weathers medium orange gray, medium bedded, no apparent fossils, forms pale yellow orange slope with sandstone and minor limestone ledges.

13. Sandstone, medium light gray, . 6.0. 135.2.
weathers medium dark brownish gray, fine to coarse-grained, with granular sized clasts, 5% weathered feldspar, well cross bedded, channel of medium-grained sandstone cut into coarse-grained sandstone, possible current direction S 70 E, sandstone fines upward, forms cliff.

12. Covered interval and sandstone;. 53.5. 188.7.
sandstone, very fine-grained, slightly calcareous, very well indurated, medium brownish gray, weathers medium grayish brown, forms ledges, at 34.5 m is very fine-grained sandstone, about 3.5 m thick. covered interval is probably siltstone or mudstone ,weathers medium gray orange, forms slope with two ledges.

Base of upper member of the North Horn Formation and top of the lower member of the North Horn Formation.

Thickness of the uppe: member of the North Horn Formation . . . 188.7.

11. Covered slope, soil weathers medium. 5.0. 5.0.
brownish gray, probably siltstone and mudstone, 1 m of limestone rip-up conglomerate at top of the unit, forms slope.

10. Sandstone, medium light brown gray,. 16.5. 21.5.
weathers medium brown gray, very coarse-grained to conglomeratic, fines upward to fine-grained sandstone, less than 1% black chert, 1-2% weathered feldspar, cross bedded, black chert helps cross beds to show up, limonitic staining, cross sets from 1.5 m to 0.2 m high, most are 0.2 to 0.5 m high, abundant wood fragments in outcrop up to 0.6 m long, possible current direction--N90E, lensing beds--probably channels, soft sediment deformation, forms cliff to ledge.

9. Covered interval, probably the same as unit three, forms slope.

8. Sandstone, medium orange brown, . 8.5. 38.5.
weathers medium orange brown, medium-grained, interbedded with fine-grained sandstone, cross bedded, mostly quartz, 1-2% weathered feldspar, possible current direction S 70 E, medium to thick bedded, laminar cross beds near the top (upper meter), forms cliff to ledges.

7. Covered interval, medium gray soil,. 15.5. 54.0.
probably same as unit three, forms slope.

6. Sandstone, medium orange gray, . 6.5. 60.5.
weathers medium dark orange brownish gray, medium-grained to very coarse-

grained, lower 3 m are medium-grained sandstone, 5% limonite, 1-2% weathered feldspar kaolin, cross-bedded, medium to thick bedded, upper three meters is medium-grained sandstone with lenses of coarse to very coarse sandstone, some thin beds are almost conglomeratic, with clay rip-up pebbles, about 8 mm in diameter, friable, cliff to ledge former.

5. Covered interval, probably the same as unit three, forms slope.

4. Sandstone, has salt and pepper look,. 5.0. 72.0.
very light gray (almost white), weathers light gray, medium to fine-grained, dark grains are proabably black chert, also some weathered feldspar, fine-grained has some black chert, but not as much as medium-grained sandstone, due to limonitic staining some crossbeds are very obvious, medium to thick bedded, friable, in fine-grained sandstone some ripple marks that show current direction N 120 E possible, possible channel lenses in fine-grained sandstone, ledge to cliff former.

3. Covered interval, probably shale, and siltstone with minor sandstone, small pieces of medium-grained sandstone appears as float, slope former.

2. Sandstone, medium orange gray, . 4.5. 142.50.5.
weathers medium dark brownish gray, medium-grained, abundant limonite, dark gray chert-1%, 5% kaolin from weathered feldspar, poor outcrop, very friable, very thick bedded, possible cross-beds, forms ledge to slope.

1. Covered interval, probably shale or silty shale slope former.

Base of the lower member of the North Horn Formation and top of the upper member of the Price River Formation.

Total thickness of the lower member of the North Horn Formation . . . 148.5.

Price River Formation and Castlegate Sandstone

This section was measured in the left fork of Deadman Canyon starting at the top of the Blackhawk Formation. The outcrop is located at the base of the massive Castlegate sandstone cliff at the junction of the first major canyon to the right in the left fork. NE1/4, NE1/4, Section 12, T13S, R10E.

Base of the lower member of the North Horn Formation and top of the upper member of the Price River Formation.

6. Sandstone, minor shale, medium light gray, weathers same, medium to coarse--grained, lenticular bedded, looks like Castlegate sandstone, first sandstone

cliff 16.5 m thick, shale forms steep slope, shale interbedded with sandstone, sandstones in this slope are about 1 to 1.5 m thick, slope is 12.0 m thick, upper cliff is 12.5 m thick, same as lower sandstone in this unit, forms ledge to cliff.

Base of the upper member of the Price River Formation and top of the lower member of the Price River Formation.

Thickness of the upper member of the Price River Formation. . . 41.0.

5. Shale, minor coal, sandstone; shale , carbonaceous, medium gray, forms covered slope; at 1.5m is coal, 0.1 m thick; at 3.0 m is sandstone, medium gray, weathers medium grayish brown, forms slope and ledge.
4. Sandstone, and shale; weathers medium pale yellow orange; sandstone, medium-grained, 90% quartz, 5% lithic fragments, minor feldspar and chert, medium bedded, forms ledge and cliff.
3. Sandstone and shale; sandstone weathers medium light pale yellow; shale weathers medium dark gray, at 5.0 m is abundant hematite staining and minor concretions; at 9 m is 1.5 m bed of carbonaceous shale, shale is more abundant in lower half of the unit and sandstone is dominant in upper half of the unit, forms slope.

Base of the Price River Formation, top of the Castlegate Sandstone.

Total thickness of the lower member of the Price River Formation. . . 42.0.

2. Sandstone, very light gray, weathers medium light gray, medium to coarse--grained, predominantly quartz, silica and calcite cemented, lenticular bedding, at 1.5 m are ripple marks, possible current direction of N 80 E, abundant cross beds at 6 m, forms cliff.
1. Sandstone, very light gray weathers light gray, 95% quartz, 1% black chert, 4% weathered feldspar-kaolin, lenticular bedded, some cross beds, abundant wood fragments in upper meter of the unit, forms ledges and very steep slope.

Base of the Castlegate Sandstone top of the Blackhawk Formation.

Total thickness of the Castlegate Sandstone. . . 77.0.

Blackhawk Formation (Aberdeen through upper mudstone members)

This section was measured at the old Sutton Mine area up an eastern tributary to Deadman Canyon (SE1/4, NE1/4, Sec.18, T13S, R11E). The section was started at the base of the lowest Aberdeen Sandstone tongue and was continued to the base of the Castlegate Sandstone.

Top of the upper mudstone member of the Blackhawk Formation and base of the Castlegate Sandstone.

23. Covered and burned interval,some ironstone concretions near top of unit, several minor sandstone ledges;, sandstone weathers gray orange, medium to fine-grained, cross-beds, possible cut and fill structures, one minor calcareous siltstone bed near the top of the member, probably coal shale, siltstone, and mudstone under cover, forms slope with minor sandstone ledges.

Base of the upper mudstone member and top of the Sunnyside Member.

Thickness of the upper member of the Blackhawk Formation.. . . 71.0.

22. Sandstone, weathers medium gray brown, light gray and light red, partially oxidized, fine to medium-grained, coarsens upward, intense to weak bioturbation,hummocky cross beds in lower 10 m, trough cross beds in next 6 m, upper 2 m are horizontally stratified, wood fragments, forms cliff.
21. Covered interval, probably siltstone and sandstone, weathers gray and medium orange brown.

Base of the Sunnyside Member and top of the lower mudstone member.

Thickness of the Sunnyside Member of the Blackhawk Formation. . . 21.0.

20. Siltstone, sandstone, coal; siltstone, weathers medium brownish gray, laminated, carbonaceous; sandstone, weathers medium brownish gray, fine-grained, cross bedded, soft sediment deformation, lenticular shaped beds; coal seam at 1 m, .1 m thick, forms slope with minor sandstone ledges.
19. Sandstone, weathers medium orange. 3.3. 18.1.
brown, medium to fine-grained, minor clay pebble conglomerate near top of bed, thin bedded, cross bedded, lenticular beds, forms cliff.
18. Shale, sandstone; shale, medium gray, weathers gray orange, thin bedded, carbonaceous, silty; sandstone, weathers medium orange brown, very fine--grained, carbonaceous, very thin bedded, forms slope.
17. Coal, mostly covered, weathers very dark gray, roof and floor rock is carbonaceous shale, ROCK CANYON COAL.
16. Same as unit 13.. 2.6. 24.1.
15. Sandstone and shale; sandstone,. 7.5. 31.6.
orange weathers same, fine-grained, 3% limonite and weathered feldspar, cross bedded, lentiular beds; shale, carbonaceous, weathers medium brownish gray, forms cliffs with minor shale recess.
14. Siltstone, weathers medium gray, thin bedded, minor carbonaceous material, minor very fine-grained sandstone lentils.
13. Coal, black weathers black, roof and floor rock are siltstone, GILSON COAL.
12. Siltstone, same as unit 9.. 1.6. 48.1.
seam, shale and siltstone are carbonaceous.
11. Sandstone, shale; sandstone weathers pale yellow orange, very fine--grained, disseminated organic material, directional ripple marks, cross bedded, soft sediment deformation, lenticular beds; shale weathers medium gray, carbonaceous, laminated, minor ironstone concretions, forms cliff with minor shale recesses.
10. Coal, black weathers black, silty, roof and floor rock are carbonaceous shale, forms covered slope.
9. Shale, weathers very dark gray, thin bedded, carbonaceous, forms slope.
8. Siltstone, sandstone,; siltstone weathers medium brownish gray; sandstone weathers medium gray orange, fine-grained, very thin bedded, lenticular, bivalve zone at 3.2 m, forms slope.
7. Coal, black weathers black, forms covered slope, KENILWORTH COAL.
6. Shale, weathers medium gray, very thin bedded, forms covered slope, carbonaceous.

Base of the lower mudstone member and top of the Kenilworth Member.

Thickness of the lower mudstone member of the Blackhawk Formation. . .
70.0.

5. Sandstone, medium gray brown, weathers, medium orange brown, becomes light gray in upper 3.0 m, fine to medium-grained, coarsens upward, weak to intense bioturbation that decrease upward, hummocky beds in lower 15 m, trough cross beds dominant in middle 6 m, laminar horizontal beds in uppermost 1 m, medium

to thick bedded, forms cliff.
4. Siltstone, shale, sandstone; mostly covered interval, siltstone,and shale, weather medium gray, carbonaceous, laminated; sandstone,weathers medium gray orange, very fine to medium-grained, lenticular, very thin bedded, interbedded with siltstone and shale, forms slope.
3. Coal, weathers very dark gray, carbonaceous shale below and thin sandstone and carbonaceous shale above, CASTLEGATE "B" COAL.
2. Same as unit 4.. 13.5. 42.0.
1. Coal, weathers black, sandstone below and carbonaceous shale above, forms covered slope.

Base of the Kenilworth Member and top of the Aberdeen Member.

Thickness of the Kenilworth Member.. . . 43.5.

6. Sandstone, medium gray brown, weathers medium orange brown and light gray in uppermost 3.0 m, Fine to medium-grained, coarsens upward, 2% black chert, 2% limonite, 1% weathered feldspar, weak to intense bioturbation that decreases upward, burrows--Ophiomorpha, vertical annelid worm smooth tubes, "swiss cheese" appearance, medium to thick bedded, hummocky and horizontal bedding, trough cross beds, uppermost 1 m is horizontally bedded, forms cliff.
5. Same as unit 6 of the this Member.
4. Covered interval, probably shale. weathers medium gray brown, forms steep slope.
3. Interbedded siltstone and Sandstone,. 4.5. 39.6.
sandstone, weathers medium pale yellow orange, fine-grained, abundant organic detritus, intensely bioturbated, hummocky and horizontal beds; siltstone, weathers medium brownish gray, intensely bioturbated, forms cliff with siltstone forming recesses.
2. Covered interval probably shale;. 5.0. 44.6.
similar to unit 4, weathers medium gray, forms steep slope.
1. Sandstone, siltstone, same as unit 3 of this member.

Base of the Aberdeen Member top of Mancos Shale (tongue).

Thickness of the Aberdeen Member of the Blackhawk Formation.. . . 47.6.

Blackhawk Formation (Spring Canyon Member), Star Point Sandstone, Mancos Shale (tongues)

This section was measured 1 km east of Deadman Canyon road near the mouth of Deadman Canyon. The section was started at the base of the Panther Sandstone tongue and measured up slope to the base of the first Aberdeen Sandstone. SW1/4, SE1/4, Sec. 18, T13S, R11E.

Base of the Aberdeen Member top of Mancos Shale tongue.

8. Covered slope, probably siltstone, weathers medium brownish gray, forms steep slope.

Base of the Mancos Shale tongue and top of the Spring Canyon Member of the Blackhawk Formation.

Total thickness of the Mancos Shale tongue.. . . 40.0.

7. Sandstone and interbedded siltstone. 10.5. 10.5.
stone, sandstone weathers pale yellowish orange, very fine-grained, intensely bioturbated, hummocky and horizontal stratification, abundant carbonaceous detritus; siltstone, weathers medium grayish brown, forms cliff with shale forming recesses in cliff.
6. Covered interval, possibly shale. 8.8. 19.3.
of siltstone, forms slope.
5. Sandstone interbedded with silty sandstone, medium dark gray, weathers medium light pale yellow orange, fine-grained, intensely bioturbated, most bedding destroyed due to bioturbation, hummocky stratification, flat stratification, bioturbation decreases near the top of the unit, forms ledges and cliffs.
4. Covered interval covered with talus. 5.3. 31.1.
from above, soil medium light yellow orange, probably silty shale or siltstone, forms slope.
3. Sandstone, medium light brownish gray, weathers medium light orange yellow, fine-grained, thick to very thick bedded, at 8.1 m are ripple marks, zones of bioturbation, burrows include Ophiomorpha, hummocky stratification.
2. Interbedded sandstone and silty sandstone, medium light gray, weathers medium light pale yellow orange, botryoidal weathering, probably highly bioturb-

ated, thin to medium bedded with siltstone laminated partings, occasional hummocky beds, forms cliff--sandstone forms siltstone forms recesses in cliff.

Base of the Blackhawk Formation and top of a Mancos Shale tongue.

Total thickness of the Spring Canyon Member of the Blackhawk Formation . . . 46.5.

1. Covered interval, covered with talus and debris from above, where not covered soil is medium light bluish gray, about 15 m from top of unit is a sandstone ledge .5 m thick, very fine-grained sandstone, covered interval forms slope.

Top of Star Point Sandstone Panther Sandstone tongue base of Mancos Shale tongue

Total thickness of Mancos Shale tongue . . . 136.0.

2. Sandstone, medium dark gray,weathers medium light orange yellow, very fine--grained, disseminated orgainc material, many burrows that are 0.5 to 1 cm in diameter, horizontal and vertical smooth tube burrows Opiomorpha, forms cliff.
1. Sandstone interbedded sandy siltstone, medium light gray, weathers medium light pale yellow orange, fine-grained, 2% particulate organic matierial, ripple marks in laminated sandy siltstone, upper 0.4 m is bioturbated, burrows 0.5 cm to 1 cm long, smooth tube type burrows, minor hummocky stratification, forms cliff.

Base of the Star Point Sandstone and top of the Mancos Shale

Total thickness of the Star Point Sandstone, Panther Sandstone tongue . . . 15.3.

Mancos Shale

The section was measured in the central part of the area at Coal Creek. Only a partial section was measured. Starting point was near the southern boundary of the quadrangle 1 km due west of bridge crossing a dry wash. The section was started at the base of a prominent Mancos bluff. SE1/4, SW1/4, Section 9, T14S, R11E.

7. Covered interval, covered with pediment gravels, slope wash, and stream alluvium,forms slope.
6. Siltstone, sandy, dolomitic, medium gray, weathers medium orange brown, limonite stained, abundant organic material forms ledge.
5. Covered interval, soil is bluish gray, probably medium dark gray siltstone and silty shale, forms slope.
4. Sandstone, silty, calcareous, medium grayish brown, weathers medium light gray orange, very fine-grained, small scale crossbedding, ripple marks, echinoderm mold, burrows 6 mm in diameter, parallel to bedding and vertial, forms ledge.
3. Covered interval, same as unit 1.
2. Siltstone and sandstone, calcareous, medium gray, weathers medium light gray, sandstone weathers medium light pale yellow orange, disseminated organic material, fine-grained, 5%lithic fragments, minor bioturbation, burrows small,-less than 3 mm in diameter, forms ledge.
1. Covered slope, covered with slope wash, probably medium blue gray shale and silty shale.

Partial thickness of the Mancos Shale. . . 563.5.

REFERENCES CITED

AAA Engineering, 1979, Coal resources and occurence and coal development potential maps of the Deadman Canyon Quadrangle, Carbon County, Utah: U.S. Geologic Survey Open-File Report 79-149.

Abbott, W. O., and Liscomb, R. L., 1956, Stratigraphy of the Book Cliffs in east-central Utah, in Geology and Economic Deposits of east central Utah: Intermountain Association of Petroleum Geologists Guidebook 7th Annual Conference, p. 120-23

Albee, J. F., 1979, Geophysical and lithologic logs of two holes drilled in the Book Cliffs Coal Field, Deadman Canyon Quadrangle, Carbon County, Utah: U.S. Geological Survey, Open-File Report 79-728, 11 p.

American Society for Testing and Materials, 1977, Standard specifications for classification of coals by rank, in Gaseous fuels, coal, and coke; atmospheric analysis: ASTM Publication D, p. 388-77.

Anderson, P. B., 1978, Geology and coal resources of the Pine Canyon Quadrangle, Carbon County, Utah: M.S. thesis, University of Utah,130 p.

Balsley, J. K., 1982, Cretaceous wave-dominated delta systems: Book Cliffs, east central Utah: American Association of Petroleum Geologists Guidebook, 219 p.

Carter, T. E., 1977, Pediment development along the Book Cliffs, Utah and Colorado: Geological Society of America Abstracts with Programs, v. 5, p. 714.

Clark, F. R., 1928, Economic geology of the Castlegate, Wellington and Sunnyside Quadrangles, Carbon County, Utah: U.S. Geological Survey Bulletin 793, p. 1-16

Cobban, W. A., and Reeside, J. B., Jr., 1952, Correlation of the Cretaceous formations of the Western Interior of the United States: Geological Society of America Bulletin, v. 63, n. 10, p. 1011-1143.

Dickinson, K. A., Berryhill, H. L., and Holmes, C. W., 1972, Criteria for recognizing ancient barrier coastlines, in Recognition of ancient sedimentary environments: Society of Economic Paleontologists and Mineralogists, Special Publication, 16, p. 192-214.

Doelling, H. H., 1972, Central Utah coal Fields: Sevier, Sanpete, Wasatch Plateau, Book Cliffs, and Emery: Utah Geological and Mineralogical Survey Monograph 3, p. 1-496.

Fisher, D. J., 1936, The Book Cliffs coal field in Emery and Grand Counties, Utah: U.S. Geological Survey Bulletin 852, p. 1-102.

Fisher, D. J., Erdmann, C. E., and Reeside, J. B., 1960, Cretaceous and Tertiary formations of the Book Cliffs, Carbon, Emery, and Grand Counties, Utah, and Garfield and Mesa counties, Colorado: U.S. Geological Survey Professional Paper, 80 p.

Gilliland, W. J., 1951, Geology of the Gunnison Quadrangle, Utah: University of Nebraska Studies, no. 8, 101 p.

Hale, L. A., 1959, Intertonguing Upper Cretaceous sediments of northeastern Utah-northwestern Colorado, in Guidebook Eleventh field conference, Washakie, Sand Wash, and Piceance Basins: Rocky Mountain Association Geologists, p. 55-56.

Harms, J. C., et at, 1975, Depositional environments as interpreted from primary sedimentary structures and stratification sequences: Society of Economic Paleontologists and Mineralogists, Short Course 2, 161 p.

Heward, A. P., 1981, A review of wave-dominated clastic shoreline deposits: Earth Science Review, v. 17, p. 223-276.

Howard, J. D., 1966a, Upper Cretaceous Panther Sandstone Tongue of east--central Utah, its sedimentary facies and depositional environments: Brigham Young University unpublished Ph. D. thesis, 155 p.

Howard, J. D., 1966b, Sedimentation of the Panther Sandstone tongue, in Central Utah coals-A guidebook prepared for the Geological Society of America and associated societies: Utah Geological and Mineralogical Survey Bulletin 80, p. 23-33.

Howard, J. D., 1966c, Characteristic trace fossils in Upper Cretaceous sandstones of the Book Cliffs and Wasatch Plateau in Central Utah coals-A guidebook prepared for the Geological Society of America and associated societies: Utah Geological and Mineralogical Survey Bull. 80, p. 35-53.

La Rocque, A. L., 1960, Molluscan faunas of the Flagstaff Formation of central Utah: Geological Society of America Memoir 78, 100 p.

Maberry, J. O., 1971, Sedimentary features of the Blackhawk Formation (Cretaceous) in the Sunnyside District, Carbon County, Utah: U.S. Geological Survey Professional Paper 688, 42 p.

Maxfield, E. B., 1976, Foraminifera from the Mancos Shale of east-central Utah: Brigham Young University Geology Studies, v. 23, pt. 3, p. 67-162.

McGookey, D. P., 1960, Early Tertiary stratigraphy of part of central Utah: American Association Petroleum Geologists Bulletin v. 44, no. 5, p. 589-615.

Nethercott, M. A., 1983, Geologic map of the Deadman Canyon 7 1/2 Minute Quadrangle, Carbon County, Utah: Utah Geological and Mineralogical Survey, in press.

Osterwald, F. W., Maberry, J. O., and Dunrud, R. C., 1981, Bedrock, surficial, and economic geology of the Sunnyside coal mining district, Carbon and Emery Counties, Utah: U.S. Geological Survey Professional Paper 1116, p. 15-44.

Parker, L. R., 1976, The paleoecology of the fluvial coal-forming swamps and associated floodplain environments in the Blackhawk Formation (Upper Cretaceous) of central Utah: Brigham Young University Geology Studies, v. 22, pt. 3, p. 99-116.

Reading, H. G., 1978, Clastic shorelines, in Sedimentary Environments and Facies: Elsevier p. 143-176.

Reinick, H. E., and Singh, I. B., 1973, Depositional Sedimentary Environments: Springer-Verlag, 439 p.

Rich, J. L., 1935, Origin and evolution of rock fans and pediments: Geological Society of America Bulletin , v. 46, p. 999-1024.

Richardson, G. B., 1909, Reconnaissance of the Book Cliffs coal field: U.S. Geological Survey Bulletin 371, p. 16-19.

Runyon, D. R., 1977, Structure stratigraphy, and tectonic history of the Indianola Quadrangle, central Utah: Brigham Young University Geology Studies, v.24, pt. 2 , p. 63-82.

Ryder, R. T., Fouch, T. D., and Elison, J. H., 1976, Early Tertiary sedimentation in the western Uinta Basin, Utah: Geological Society of America Bulletin 87, p. 496-512.

Sabins, F. F., 1962, Grains of detrital, secondary, and primary dolomite from Cretaceous strata of the Western Interior: Geological Society of America Bulletin , v. 73, p. 1183-1196.

Schoff, S. L., 1937, Geology of the Cedar Hills, Utah: Ohio State University Abstracts of Doctoral Dissertations 25, p. 375-386.

Spieker, E. M., 1931, The Wasatch Plateau coal field, Utah: U.S. Geological Survey Bulletin 819, 210 p.

Spieker, E. M., 1946, Late Mesozoic and early Cenozoic history of central Utah: U.S. Geological Survey Professional Paper 205-D, p. 117-161.

Spieker, E. M., 1949, Sedimentary facies and associated diastrophism in the upper Cretaceous of central and eastern Utah, in Longwell, C. R., (Chm.), Sedimentary facies in geologic history (Symposium): Geological Society of America Memoir 39. p. 55-81.

Spieker, E. M. and Reeside, J. B., Jr., 1925, Cretaceous and Tertiary formations of the Wasatch Plateau, Utah: Geological Society of America Bulletin, v. 36, no.3, p. 435-454.

Stanley, K. O., and Collinson, J. W., 1979, Depositional history of Paleocene-Lower Eocene Flagstaff Limestone and coeval rocks, central Utah: American Association of Petroleum Geologists Bulletin, v. 63, no. 3, p. 311-323.

Taff, J. A., 1906, Book Cliffs coal field, Utah, west of Green River: U.S. Geological Survey Bulletin 285, p. 239-302

U.S. Geological Survey, 1976, Coal resource classification system of the U.S. Bureau of Mines and U.S. Geological Survey: U.S. Geological Survey Bull. 1450-B, 7p.

Van De Graff, F. R., 1969, Depositional environments and petrology of the Castlegate Sandstone (Cretaceous), east central Utah: Ph. D. dissertation, University of Missouri, 88 p.

Van De Graff, F. R., 1972, Fluvial-deltaic facies of the Castlegate Sandstone (Cretaceous), east-central Utah: Journal of Sedimentary Petrology, v. 42, no. 3, p. 558-571.

Witkind, J. J., 1979, Reconnaissance geologic map of the Wellington Quadrangle, Carbon County, Utah: U.S. Geol. Survey Misc. Investigations Series, Map I-1178.

Young, R. G., 1955, Sedimentary facies and intertonguing in the upper Cretaceous of the Book Cliffs, Utah-Colorado: Geological Society America Bulletin, v.66, p. 177-201.

Young, R. G., 1957, Late Cretaceous cyclic deposits, Book Cliffs, eastern Utah: American Association Petroleum Geologists Bull., v. 41, p. 1760-1774.

Young, R. G., 1966, Stratigraphy of coal-bearing rocks of Book Cliffs, Utah--Colorado, in Central Utah coals, -A guidebook prepared for the Geological Society of America and associated societies: Utah Geological and Mineralogical Survey Bulletin 80, p. 7-21.

Young, R. G., 1973, Depositional environments of basal Cretaceous rocks of the Colorado Plateau, in Cretaceous and Tertiary rocks of the Southern Colorado Plateau: Four Corners Geological Society Memoir p. 10-27.

Young, R. G., 1976, Genesis of Western Book Cliffs coals: Brigham Young University Geology Studies, v. 22, pt.3, p. 3-14.

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